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Rapid Method of Approximating the Area of a Hysteresis Loop . . . . RALPH A. SAWYER
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Count Rumford: Soldier, Statesman, Scientist

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MARCH 26 will mark the anniversary of the birth of a contemporary and namesake of Benjamin Franklin whose colorful career was to rival his in variety and achievement, if not in lasting fame. There still stands in North Woburn, near Boston, the old frame house that saw in 1753 the birth of Benjamin Thompson.

Even as a youth of 14, apprenticed to the proprietor of a variety store in Salem, he reveals the traits of boundless energy and ambition which are to carry him far, traits reflected in a letter written by his guardian to his employer:

> "[Thompson] saith he . . . hath Sum priuyledge of trade for him Self, and that you, Sir, would let him haue Sum fish to Ship, if I would send you an order for them."

Already a skilled draughtsman and designer, the inventor of a perpetual-motion machine which did everything except work, and an ardent student of mathematics and astronomy, he undertook so zealously the preparation of some fireworks for the local celebration of the repeal of the Stamp Act that an accidental explosion sent him home with painfully severe if not permanent injuries. During his convalescence he is said to have walked the eight miles from Woburn to Cambridge for the science lectures at Harvard College which he was permitted to attend, afterwards repeating the experiments at home.

At 16 he transferred his apprenticeship to Boston, where, his memorandum-book reveals he allotted himself six hours per day for studies ranging from chemistry and physics to anatomy and surgery, having just begun the study of medicine with a Woburn physician. Additional entries in the book include attendance records at a "French School to Learn the French Language" and illustrated "Directions for the Back Sword," as well as a recipe for making rockets which closes with the somewhat irrelevant reflection: "Love is a Noble Passion of the Mind. LOVE."

His zealous studies won for him a position teaching school at Concord, New Hampshire, then incorporated as Rumford (the name from which he later drew his title), where, at 19, he married a wealthy widow nearly fifteen years his senior—"was married," he later averred, thus placing the burden of suit upon her. His acceptance of Governor Wentworth's offer of a majorship in the Second Provincial Regiment of New Hampshire aroused considerable ill will among the subordinate officers—but Thompson was never one to let the feelings or respect of others stand in the way of his advancement.

He early affirmed his sympathy for the Patriot cause, and besides assisting in the removal of books from the Harvard College Library to a place of safety, so that the buildings of "The University at Cambridge" might be used as barracks, he is said to have petitioned George Washington for a post in the American army. But regarded with increasing hostility as "unfriendly to the cause of Liberty," and never, in truth, popular with his neighbors, he finally boarded a British frigate and, after the British

forces' evacuation of Boston, accompanied it to England as the bearer of dispatches from General Howe. He never returned to his wife and infant daughter.

In London, having definitely allied himself with the Royalist cause, he soon won the position of Undersecretary of State, besides membership in the Royal Society "as a gentleman well versed in natural knowledge and many branches of polite learning." Honored at 28 with the commission of Lieutenant-Colonel, he commanded a regiment of cavalry called the King's American Dragoons, and served with them in South Carolina against the free-lance Marion. During an extended period of service on Long Island, he greatly vexed the people of Huntington by ruthlessly erecting a fort on a vantage point in the center of the public burying ground, even compelling the villagers to assist in pulling down the Presbyterian Church for use as material in the fort. The tombstones were employed in building fireplaces and ovens, and a local historian reports the testimony of men who

> "had seen the loaves of bread drawn out of these ovens with the reversed inscription of the tombstones of their friends on the lower crust."

Upon his return to England in 1783 he was retired from the army with the rank and half-pay of Colonel. Provided with permission to visit the Continent, he set out in hopes of further military successes, crossing the Channel on the same vessel with the historian Edward Gibbon—who impressively refers to him in correspondence as "Mr. Secretary, Colonel, Admiral, Philosopher Thompson." While visiting Munich and Vienna, he received an invitation to enter the service of the Elector of Bavaria, Charles Theodore. King George III not only gave his consent but honored Thompson with knighthood for "his good Conduct and Bravery in the Line of his Profession."

As Colonel of a regiment of cavalry and Aide-de-Camp to the Elector of Bavaria, Sir Benjamin resided in a palatial edifice in Munich attended by a whole staff of servants. He devoted himself to learning the German and French languages and to familiarizing himself with all that concerned the Elector's dominions. By 1788 he was a Major General of cavalry, Privy Councillor of State, and head of the War Department. His election to membership in the Berlin, Mannheim, and Munich Academies, in recognition of his scientific investigations in water and heat, was climaxed, in 1791, with his becoming Count of the Holy Roman Empire, with his title chosen from the New England town of Rumford.

With careful forethought and scrupulous attention to details, Count Rumford inaugurated many far-reaching political and social reforms. In hopes of "making soldiers citizens, and citizens soldiers" he introduced a new system of order, discipline, and economy among his troops, whereby their pay was increased and their quarters improved, individual gardens and a military academy provided, and the soldiers

Rumford's birthplace, North Woburn, Massachusetts.

occupied in public works on the highways, marshes, rivers which more than paid for their support.

Ever hopeful of "diminishing, as much as possible, at all times, . . . the misery of the lower classes of the people," Rumford set up an Establishment for the Poor at Munich. Enlisting the army and public opinion in his fight to suppress the plague of mendicity then prevalent, he seized in a single week no less than 2,600 beggars, out of a population of only 60,000 in Munich at that time, and gave them attractive quarters, education, and remunerative textile employment in the House of Industry. Parts of his still interesting "Fundamental Principles . . . for the Relief of the Poor . . ." read like pages from the New Deal, so modern is his message of common sense:

"*All sums of money or other assistance given to the poor in alms, which do not tend to make them industrious, never can fail to have a contrary tendency, and to operate as an encouragement to idleness and immorality.*"

"The most certain and efficacious relief . . . is . . . by forming a general establishment for giving them useful employment, and furnishing them with the necessaries of life at a cheap rate."

"Quite surprising, and at the same time interesting in the highest degree, was the apparent and rapid change . . . in their manners, in their general behaviour, and even in the very air of their countenances, upon being a little accustomed to their new situations."

The poor people, upon several occasions, showed their affection for him by filing in procession to the cathedral to pray for his recovery from ill health brought on by overwork.

Over a considerable period of time, by indefatigable investigation and economy, he made this great venture pay for itself. First, after carefully studying the construction of public kitchens and the current methods of cooking and heating in open fireplaces, he observed that seven-eighths of the heat generated was wasted; and by ascertaining experimentally the correct angles and size of the most economical fireplace and chimney, he thereby not only effectively reduced the amount of fuel consumed but also eliminated the prevailing curse of smoking chimneys. His *Essays* give extensive and still useful information on and directions for the construction or improvement of fireplaces and chimneys, as well as a general treatment of the principles of combustion, ventilation, and draughts. Stating, boldly for his day, "I am even sanguine enough to expect that the time will come when open fires will disappear, even in our dwelling-rooms and most elegant apartments," he finally evolved a "closed fire-place" and "portable kitchen-furnace" which were the ancestors of the modern cooking stove, and a "steam-stove" for heating rooms which resembles the modern furnace. He invented "The Rumford Roasters," which were used extensively in Great Britain and America, and a "coffee boiler" which is little different from the modern coffee pot. For none of these inventions did he apply for a patent, as he was desirous of placing his discoveries at the service of even the poorest of his fellow men.

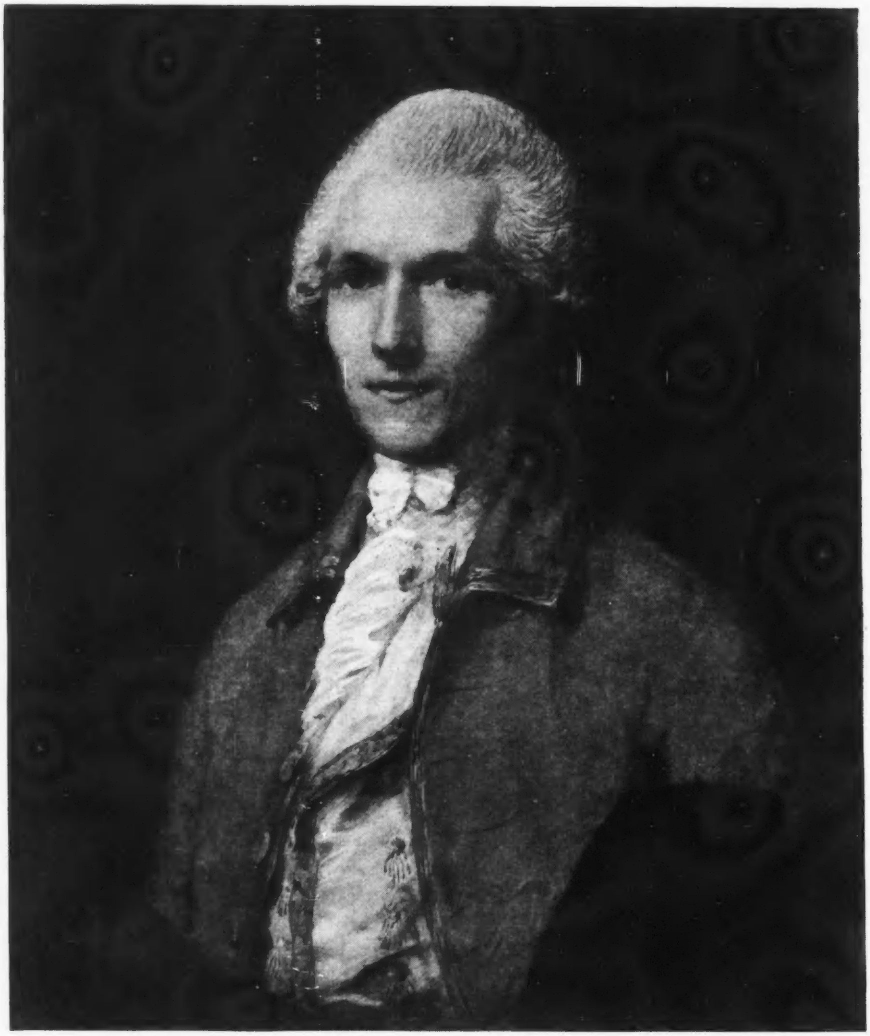
Next he turned to the study of the selection and preparation of food, firmly convinced of

"the infinite advantages to the human species that might be derived from a more intimate knowledge of the science of preparing food."

"The poor might be fed from a public kitchen for *less than half* what it would cost them to feed themselves."

He was especially desirous of importing cheap foods and dishes from other countries, and was successful in popularizing many which were either unknown or regarded with disfavor at that time in Bavaria. Among these were the potato, Indian corn, and macaroni. Not content with bringing in these foods, he carefully studied their preparation. Though protesting that "few persons are less attached to the pleasures of the table than myself," he devotes considerable space in his *Essays* to this subject. His directions for eating hasty pudding in the American manner are so detailed as to be amusing:

"The hasty pudding being spread out equally upon a plate while hot, an excavation is made in the middle of it with a spoon, into which excavation a piece of butter as large as a nutmeg is put, and upon it a spoonful of brown sugar, or more commonly of molasses. The butter being soon melted by the heat of the pudding mixes with the sugar or molasses, and forms a sauce, which, being confined in the excavation made for it, occupies the middle of the plate. The pudding is then eaten with a spoon, each spoonful of it being dipped into the sauce before it is carried to the mouth; care being had, in taking it up, to begin on the outside or near the brim of the plate, and to approach the centre by regular advances, in order not to demolish too soon the excavation which forms the reservoir for the sauce."



This portrait of Count Rumford at the age of 30, by Thomas Gainsborough, is termed "one of the great English artist's finest achievements in male portraiture." It hangs in the Fogg Museum of Harvard University.

So much for his contribution to the art and science of the epicure. Among his sundry other activities can be mentioned here only such as his investigations in clothing, light and illumination, colors; his experiments in gunpowder and firearms; his efforts in improving the breed of horses and horned cattle; his success in reducing interest rates; and his creation of the attractive "English Garden" out of a wild and neglected region on the outskirts of Munich, in which the citizens erected a large stone monument to his memory—still to be viewed by the visitor in Munich. Apropos of this ceaseless striving for the betterment of the realm and the gratification of his own boundless curiosity, Cuvier applied to him Fontenelle's judgment of Dodard, that he was the first man who took the same path for getting into heaven and the French Academy.

In 1795 he visited England in connection with the publication of his *Essays*. These eighteen essays, published over a long period from 1796 to 1812, firmly established his fame in both scientific and philanthropic fields. Their first American edition spread his fame to this country, hitherto but sketchily acquainted with his accomplishments. While in England he endowed medals to be presented biennially by the Royal Society of London and the American Academy of Arts and Sciences respectively, for discoveries in light and heat which would "tend most to promote the good of mankind." Reforms undertaken during visits to Ireland and Scotland brought him numerous honors which included membership in the Irish Royal Academy and the Royal Society of Edinburgh, as well as the degree of Doctor of Laws.

Upon returning to Bavaria, he was joined by his daughter Sarah (now 21 years of age), whose mother had died in Woburn some four years previously. Her correspondence describes enthusiastically the gay court life at Munich, and—less warmly—the rigorous course of studies prescribed for her by her father.

Count Rumford was appointed Minister Plenipotentiary from Bavaria to the Court of Great Britain, only to discover upon reaching London in 1798, that his English citizenship precluded his being received in a diplomatic capacity. Suffering from ill health, he purchased a villa near London and settled there instead of returning to Munich. The lapse of his forced exile from America, which had been imposed upon him by his Royalist activities, aroused his hopes of realizing a long-standing desire to visit the United States, and he even negotiated for the purchase of an estate near Cambridge, Massachusetts. But when the United States government finally offered him the post of Superintendent of the newly planned Military Academy, as well as Inspector-General of the Artillery, the Count was too busily engaged in founding the Royal Institution in London for

> "the speedy and general diffusion of the knowledge of all new and useful improvements . . .; and teaching the application of scientific discoveries to the improvement of . . . domestic comfort and convenience."

So the Count's daughter Sally was forced to return to America alone.

While taking the waters at Harrowgate for his health, experiments suggested by his ever inquisitive mind led him to forsake the prevailing custom of taking a warm bath on the eve of each third day just before retiring, in favor of daily pre-dinner bathing—"[an] experiment . . . thought to be very hazardous by many persons at Harrowgate, and even by the physician." His Essay on the subject extols "the *pleasant* effects . . . [and] the true luxury of warm bathing," though accepting the current belief in the ill effects of cold baths, and gives full directions for the construction of bathing-rooms and tubs. Particularly interesting is an enthusiastic description of Turkish baths and the use of "grateful aromatic perfumes."

The subject of heat, in its various manifestations, was his favorite and perennially engrossing study, and doubtless the one in which his name will be remembered longest. As Dr. Youmans asserts, "He was the man who first took the question of the nature of heat out of the domain of metaphysics, where it had been speculated upon since the time of Aristotle, and placed it upon the true basis of physical experiment." Rumford reports that an apple pie furnished the material for the investigations which led to his demonstrating the fallacy of the then current belief in "the free passage of Heat, in all directions, through all kinds of bodies." Having burned his mouth in eating the pie, he reflected upon "this extraordinary quality of retaining Heat which apples appeared to possess." He noted, too, as we all have, that his thick rice-soup was cooler at the surface than below; that water conducted heat much more readily than the wooden spoon he used in other experiments, and that silver or gilded teapots held the heat of liquids much longer than did those of plain porcelain. Though the Count modestly minimized the honor of discovering "those treasures which everywhere lie so slightly covered," these simple observations were the basis of researches, too lengthy for discussion here, which led to his well-known demonstration that "Heat could not be a material substance, but must be something of the nature of motion."

Missing the colorful life and exalted position which he had enjoyed at Munich, but now dis-

couraged from returning by the inconsiderable affection with which the new Elector and his advisors regarded him, Count Rumford made several visits to Paris, where, in the long course of lavish entertainments held for him, he wrote his daughter: "I made the acquaintance of [a] very amiable woman in Paris, who, I believe, would have no objection to having me for a husband, and who in all respects would be a proper match for me." This was Madame Lavoisier, widow of the great French chemist; and marry her he did, in 1805, settling in Paris. But after a year of married life he confessed sorrowfully that they were "totally unlike, and never ought to have thought of marrying," she being "one of the most imperious, tyrannical, unfeeling women that ever existed." Of course this is an unfair judgment of that brilliant idol of the salon, but it was unfortunate that her fondness for society not to his liking conflicted so sharply with his own quiet tastes as to result in many bitter quarrels. He relates that upon one occasion she invited a large party of undesirable guests solely to vex him; and when he locked them all out, she talked with them over the high brick wall of the garden, and vented her spite by maliciously pouring boiling water on some of his highly prized flowers.

Finally, leasing a villa in the Paris suburb of Auteuil, he settled there in 1809 after an amicable separation from his wife. Here, somewhat improved in health, but sadly disappointed by the utter failure of his marriage, he lived a rather lonely, restless life. As familiar with the German, French, Spanish, and Italian tongues as with his own, he nevertheless entertained few guests, amusing himself simply with his flowers and an occasional game of chess or billiards. Ever a man of abstemious habits, and a "slave to order" according to his daughter, he followed utterly the dictates of his own reason—for instance, he adopted (much to the amusement of his neighbors) a winter dress entirely of white upon discovering that more heat is lost from a dark body than from a light one.

Here his scientific investigations, described in the journals of the Institute of France, to which society he had been elected a Foreign Associate in 1803, ranged from the use of broad wheels for carts and carriages to the properties of light. One popular story relates his invention of a lamp of such great brilliance that the workman who carried it home one night to show it was so blinded by its glare that he could not see his way home and had to stay out all night in the Bois de Boulogne.

A fever, at 61, suddenly proved fatal, on August 21, 1814. The eulogies and honors showered upon him at his death, in France, England, Germany, and America, are reflected in the inscription on the monument over his grave in Auteuil: "Physicien célébré, philanthrope éclairé, ses découvertes sur la lumière et la chaleur ont illustré son nom. Ses travaux pour améliorer le sort des pauvres le feront toujours chérir des amis de l'humanité."

To Harvard University he bequeathed funds to establish a professorship in the physical and mathematical sciences "for the improvement of the useful arts, and for the extension of the industry, prosperity, happiness, and well-being of Society." This Rumford Professorship, established in 1819, is now held by Professor G. W. Pierce and valued at nearly $70,000—a rich return for the few lectures which the authorities permitted Rumford to attend as a youth.

Voltaire in France, Goethe in Germany, Swift in England, Franklin in America, Rumford in all these countries—all are typical of the best of that most interesting period aptly termed the Age of Reason. The insatiable curiosity, the critical attitude, the boundless energy, and the humanitarian interest with which Rumford and these others regarded life are the most characteristic traits of the period. These qualities of mind which constitute the contribution of that age to human understanding and culture may be summed up briefly in a few sentences chosen from his *Essays:*

> "There is nothing more dangerous than to take anything for granted, however unquestionable it may appear, till it has been proved by direct and decisive experiment." "Everything taking place before my eyes . . . immediately excites my curiosity and attracts my attention." "My principal desire in publishing these computations is to *awaken the curiosity of my readers*." "I never write, except it be to recommend to the public something which I conceive to be of importance, or to communicate the results of new experimental researches, which appear to be sufficiently curious and interesting to merit attention."

This interest in the benefit to humanity and the improvement of living standards was so constantly dominant in his pursuits that the name of Rumford became a synonym for Reform, and was used to effect the sale of many a new invention or boasted improvement.

Count Rumford's material works, such as Munich's English Garden or the street and additional monument which bear his name, are not necessary to the survival of his fame. Physicists know well how their work has been notably advanced by his sound reasoning in heat and light; housewives have had their labors in cooking eased by his invention of the modern stove; husbands have had their fuel bills measurably reduced by his careful calculations in fuel; army efficiency still borrows from his scrupulous economy; public works and other employment projects owe much of their methods to his common-sense planning; his funds and foundations still serve as a means and encouragement to further research and service to humanity. What is still more important, we can all profit by the personal example of criticism, curiosity, and service set by this humanitarian, soldier, statesman, and scientist. A sentence translated from the funeral oration at Auteuil pronounced by M. Benjamin Delessert may be quoted in closing:

> "In England, in France, in Germany, in all parts of the continent, the people are enjoying the blessings of his discoveries; and, from the humble dwelling of the poor even to the palaces of sovereigns, all will remember that his sole aim was to be always useful to his fellow men."

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Physics and the Arts

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ALTHOUGH there may be many workers in the field of physics who feel a certain timidity in the presence of the arts, nevertheless, there are few if any who wish to be known and remembered as merely pointer-reading animals. Man does much more than record pointer readings: he interprets them. And even Mr. Eddington, whose pleasant chapter has won a well-deserved popularity, would be one of the last to deny the interpretive function of the physicist as a man.

It is in the nature of things that there must be some of art in science and some of science in art, but the interpretive methods in the two realms are entirely different. Whereas the scientist must not wander too far from his pointer readings, the artist often deals with quantities far less measur-

able in which the interpretive function is of such paramount importance that the factual content is sometimes almost lost sight of. However differing thus in material and method, it should be especially noted that three of the so-called "seven arts"—namely, architecture, music, and painting—take their raw materials directly from the world of physics, and that a number of minor arts involving physics, such as the use of color and illumination, are rapidly rising in prominence. Upon the recognition of these facts the question arises as to how much attention should be paid to the implied relationship in the general physics course, or whether any attention should be paid at all.

A survey of sixteen recent textbooks of general college physics shows interesting variations in the amount of space devoted to matters of basic value in these arts. Because all texts deal to a certain degree with the fundamental mechanical elements at the basis of architectural construction, let us here interest ourselves more especially in the arts based on audible tone and visual color. In the books surveyed the space devoted to the portions of sound and optics of fundamental concern to these arts varies from as much as thirteen or fourteen pages on musical tones and their relationships, and six to eight pages on color tones and their relationships, down to zero for either or both.

Naturally there must be different types of textbooks for different types of courses, and it may be true that in some of these no space should be allotted to a consideration of the basic elements of tone and color. But the present survey leads to the unavoidable conclusion that the amount of space devoted to such matters has depended more often on the interests and propensities of the author than on the actual objective design of the text.

There are many reasons why a brief but satisfactory statement of the physical basis of color theory should form as integral a part of the general course as does a statement of the physical basis of music. Color is more immanent than music in nature and man-made color effects are certainly fast approaching the importance of man-made musical effects. The present greater emphasis on treatments of the physical basis of music is perhaps due partly to the fact that nearly every community has had its brass band, its striving musicians and its critical listeners. On the other hand, while the enjoyment of color has been widespread in the general way, people have been strangely unobservant, in any refined or critical sense, of the world of colors about them. Until recently few places have had art galleries where good paintings could be seen and for years the vogue of the black and white reproduction was widespread; in fact, the influence of the old colored chromo was such that many people of a generation or so ago thought that there was something inherently vulgar about color and that only in black and white or sepia could real refinement be found.

That we tend to travel in circles can be seen by going back to the texts of an earlier day which allotted considerably more space to color and sound. The onslaught of "modern physics" has helped to crowd these subjects to the wall, but already the way for a return has been partly paved by the growing demand for more and broader human values in physics. One hears much of the relation of physics to industry but there is at the same time a growing need for the better formulation and understanding of the relation of physics to the arts.

Of the sixteen textbooks which were examined, four omit all mention of musical scales or their basis but, of these four, two treat color with considerable thoroughness. Four others discuss musical intervals and scales but make scant reference to color, and of these latter four, one omits all mention of color except in reference to spectra and a few phenomena quite unrelated to the arts. The remaining eight books treat both color and the physical basis of music in varying degrees, but with the emphasis on the music. In only three are there treatments of both subjects that approach adequacy and only two out of the sixteen contain definite statements of the three characteristics of a color tone. In one other text, hue is defined. In none is there any statement of what might be meant by a color scale. The majority, however, contain an analysis of the characteristics of a musical tone, and something about tone intervals and scales. Some even give descriptions of representative musical instruments, which were of course devised for anything but the production of pointer readings.

Because the physical characteristics of both color tones and musical tones are commonly described in terms of three somewhat similar independent variables (quality in music actually stands for a set of variables), it is tempting to draw a close analogy between them. A musical tone is usually described in terms of *pitch* (frequency), *intensity* (loudness), and *quality* (overtones). A color tone is described in terms of *hue* (frequency), *brightness* or *luminosity*, which corresponds to loudness in sound, and *chroma* or *saturation*. Chroma indicates the quality of grayness due to admixture of white light; it is entirely independent of hue or brightness. The whole range of visible tones may be conveniently represented by a system of cylindrical coordinates as in the Munsell system though Ives[1] recently has used a rectangular coordinate system for purposes of tri-chromatic mixture. It would take but a brief space in lecture or text to define the physical characteristics of a color tone accurately by means of these three variables and to illustrate the meaning by a simple chart.[2] There is nothing more annoying to one used to thinking in terms of these exact quantities than to hear them slurred together in the one word "color." Indeed, it is doubtful if any other term in general physics is used in so "fuzzy" and inexact a manner. The word *color*, it must be remembered, may stand for the sensation produced, or for the pigment (the artist speaks of mixing his colors) or for the physical phenomena to which we owe the sensation. It is with this last sense that the physicist should chiefly concern himself. Psychological variables are not necessarily independent though the physical variables are, as Fletcher[3] has shown in his work on sound and as is also well recognized in the case of color.

Five of the textbooks examined omit all mention of primary colors for either vision or mixing pigments. In only four texts are additive and subtractive color mixtures or the mixing of pigments discussed adequately. Six discuss color vision and color-vision primaries only. One of these six gives the colors as red, yellow, and blue; with such primaries no visible green could exist as green cannot be produced additively in the eye. One text suggests that the color-vision primaries actually are not more primary than any other colors. But in any theory of color-vision the choice of primary colors is necessarily restricted by this uniqueness of the green. In spite of the physicist's predilection for a tri-chromatic theory, however, he should not overlook the possibility of actual physical evidence for a contrary theory as adduced by Houstoun.[4]

The term *primary colors* should be used with care. Red, green and violet may be primary in a tri-chromatic theory of vision, but not in a tetrachromatic theory. The artist may use *red*, *yellow*, and *blue* as primary colors, or he may use what Ives[1] calls, from their subtractive nature, *minus green*, *minus blue* and *minus red;* but he is not limited to these of necessity as so many people seem to think. Indeed the artist may conveniently use any three colors properly spaced on the color circle, except for minor considerations of luminosity, saturation and harmony; the claim of red, yellow and blue to the title "primary" is due chiefly to the fact that greater luminosity and saturation are obtained with them. Actually he seldom limits his palette so much although Ives has demonstrated the practicality of such limitation.

Discussions of additive mixtures by means of the color-top frequently are hazy or ambiguous because of failure to define what is meant by a gray or to distinguish between the points of view of the artist and the physicist. To the former, gray means a mixture of a black and a white pigment. To the latter, who speaks in terms of illumination, a gray means merely a white of lower degree of luminosity than that taken as standard. But to the beginning student it may not be so apparent why one text states that blue and yellow mixed on the color-top give white, while another says that they give gray.

One of the texts makes an unnecessary and misleading distinction between objective and subjective color: it defines objective color as the color of a thing seen in white light; subjective color, as the color of the same object seen in any other kind of light. The physicist of course does well to avoid the psychological complications of subjective effects of color, but he should also

[1] H. E. Ives, Proc. Phys. Soc. **46**, 16 (1934).
[2] R. D. Rusk, J. O. S. A. **23**, 182 (1933).
[3] H. Fletcher, Bell. Lab. Rec. **13**, 130 (1935).

[4] R. A. Houstoun, *Vision and Colour Vision* (Longmans, Green, 1932), p. 226 ff.

recognize that all such facts of sensation *are* subjective regardless of the color of the illumination and that insofar as possible his business is to stick to objective factors.

Physicists sometimes smile at the technical mistakes made by artists and yet are not they themselves, through their textbooks, partly responsible for them? There is scarcely an art book involving any of the optics of modern painting that does not contain serious, avoidable errors. Especially to be noted are the errors made by practically all writers on impressionism, such as the confusion of additive and subtractive primary colors. Most art books refer to some of the impressionists juxtaposing small spots of pure color in order to achieve brilliance (the term "pure color" refers here to pigment direct from the tube and has nothing to do with spectral purity) and even the most prominent authors go on to choose the unfortunate example of juxtaposing spots of yellow and blue in order to produce the effect of green. Of course this is a fatal choice, for although yellow and blue pigments when mixed will give green, they are the only two colors which if mixed additively do not give the color immediately between them in the color circle but on the other hand being complementary should give a white of low luminosity. It is a simple fact to be observed by looking at any impressionist picture that in no case has green grass been painted by juxtaposed streaks of yellow and blue. How strange that this simple fact of observation should have so long escaped the critics! The writer knows of only one account of the impressionist movement, out of the many of which have been written, that was at all adequate from the point of view of optics, and this, in a well-known encyclopedia, was later supplanted by a less satisfactory one.

Only one physics text of those surveyed mentions the subject of impressionist painting and the idea of juxtaposition, although this affords an excellent example of the principle of additive mixture. Furthermore, it represents to an unusual degree a parallel development in science and art. Although many people speak of the so-called impressionist movement as if it were very modern, it actually had its beginnings in France about the time of our own Civil War. Regardless of its name, which means little and for which such names as "luminism" and "chromatism" have also been suggested, it marks the beginning not only of the modern use and appreciation of color in art but of an application of scientific principles to painting, even though these principles were not always completely understood, and of an entirely new and broad vision of color in general.

Color and color relations were studied by the Greeks, and Democritus considered that there were four primary colors—black, red, yellow and white.[5] But optical theories and artistic methods in painting were largely independent of each other up to the nineteenth century, except for the work of the brilliant and technically-minded Leonardo who recognized four *simple* colors—red, yellow, green and blue. Color theory developed but little until Newton passed sunlight through a prism and conceived the idea of arranging the colors in a circle. From that time on the scientific field of color grew, at first slowly, and then burst into activity in the nineteenth century. In physics there came to the study of color a brilliant galaxy of scientists led by Young, Chevreul, Helmholtz and Maxwell. These were followed by Rood in America, and von Bezold in Germany, who set down the new findings more understandably with reference to the arts. At the same time the movement was being paralleled in the world of painting by Delacroix and, later, Manet, followed by Monet, Renoir, Pissarro and others under the cloak of the so-called impressionist movement.

Likewise paralleling the reaction against classic formalism in painting came the demand in music—with Strauss, and Debussy and the French school—for new tonal effects. Out of the accompanying devastation, came an enrichment of musical tone in which perhaps no less than in the field of color there has been opened up a new range of possibilities; and to these should be added the results of experimentation with electrical instruments and the more flexible control of tone quality. New tonal effects in music are certainly the concern of both the physicist and the musician but little is said about such matters in the general physics text.

With the reorganization of education in process throughout the country, with the growth of the junior colleges and the present liberalization of the universities, physics must further take stock of itself in regard to its position in the educational scheme. The relations of physics to philosophy have recently received considerable attention and the many relations of physics to the arts must not be overlooked. Especially the almost forgotten field of color deserves to be recalled and reinstated in the general course.

[5] M. H. Swindler, *Ancient Painting* (Yale Univ. Press, 1929), p. 111.

On the Establishment of Fundamental and Derived Units, with Special Reference to Electric Units. Part II

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THERE is a relatively enormous literature on the subject of electric and magnetic units. However, as noted in Part I,[17] most of the papers are devoted to a discussion of the numerical relations, with little or no comment on the matter of dimensions.

The so-called absolute systems of electric and magnetic units were founded by Gauss[18] and Weber.[19] A brief, but very clear summary of these two epoch-making papers is given by Crew.[20] Although they contain no explicit discussion of the arbitrary nature of dimensions, such as that given later by Bridgman,[2] it seems evident to the writer that both Gauss and Weber were tacitly in complete agreement with Bridgman's position.

The present accepted form of the absolute electrostatic and electromagnetic systems first occurs in a report by J. Clerk Maxwell and Fleeming Jenkin, "On the Elementary Relations between Electrical Measurements," presented to the British Association Committee on Electrical Standards,[21] and adopted by this committee in its *Second Report*, 1863. The results of the work of Gauss and Weber were incorporated by Maxwell in this report, as well as in his classic treatise.[22] This latter work seems to have been, for many years, the chief source of material for textbooks in the field. In referring to the work of Gauss and Weber, Maxwell says[22] (Vol. II, p. 193),

> "The introduction, by W. Weber, of a system of absolute units for the measurement of electrical quantities is one of the most important steps in the progress of the science. Having already, in conjunction with Gauss, placed the measurement of magnetic quantities in the first rank of methods of precision, Weber proceeded in his *Electrodynamic Measurements* not only to lay down sound principles for fixing the units to be employed, but to make determinations of particular electrical quantities in terms of these units, with a degree of accuracy previously unattempted. Both the electromagnetic and the electrostatic systems of units owe their development and practical application to these researches."

That Maxwell understood the arbitrary character of dimensions is shown by his table (Vol. II, p. 267) in which, for instance, the specific inductive capacity, defined always as the ratio of D to E, is listed as having zero dimension in the electrostatic system and T^2L^{-2} dimensions in the electromagnetic system. Similarly the "magnetic inductive capacity" μ, defined as the ratio of B to H, is assigned T^2L^{-2} dimensions in the electrostatic system, and zero dimension in the electromagnetic. Nowhere in Maxwell's text do the symbols ϵ and μ appear in connection with dimensions. The first appearance that I have noted of these symbols in dimensional formulas is in Abraham-Föppl.[23] These authors, however, are in perfect agreement with Maxwell on this matter. When they give, for instance, $M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\epsilon^{\frac{1}{2}}$ as the dimensions of the unit of electric charge, they intend this as a general expression, applying to *any* system of electric units. The corresponding general expression, in terms of μ, is $M^{\frac{1}{2}}L^{\frac{1}{2}}\mu^{-\frac{1}{2}}$. To get the actual dimensions of electric charge in any given system of electric and magnetic units, one must insert the dimensions of ϵ, or of μ, in that system. Thus using the dimensions of ϵ and μ in the electrostatic system, as just given, we obtain, from either general expression, $M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}$ as the dimensions of electric charge. A similar use of the dimensions of ϵ and μ in the electromagnetic system leads to $M^{\frac{1}{2}}L^{\frac{1}{2}}$ as the dimensions of electric charge in that system. These two resulting ex-

[17] R. T. Birge, Am. Phys. Teacher, **3**, 102 (1935). The numbering of footnotes and equations in Part II follows consecutively from Part I.

[18] K. F. Gauss, "Intensitas vis magneticae terrestris ad mensuram absolutam revocata . . ." (Göttingen, 1833).

[19] W. Weber, "On the Measurement of Electric Resistance according to an absolute Standard," Poggendorff's Annalen, **82**, 337 (1851). Eng. tr. in Phil. Mag. (4) **22**, 226, 261 (1861).

[20] H. Crew, *The Rise of Modern Physics*, ed. 2 (Williams and Wilkins, 1935). Chap. XII, "The Origin of Modern Electrical Units."

[21] *Reports of the Committee on Electrical Standards, appointed by the British Association for the Advancement of Science* (Cambridge Univ. Press, 1913). This includes Reports 1–39 (1862–1912) inclusive. The Maxwell and Jenkin report occupies pp. 86–140. These authoritative reports give an extended discussion of absolute electric systems of units.

[22] J. C. Maxwell, *A Treatise on Electricity and Magnetism*, ed. 3 (1892).

[23] M. Abraham and A. Föppl, *Theorie der Elektrizität*, ed. 3 (1907), Vol. I, pp. 257–262.

pressions for the dimensions of electric charge are just those given earlier by Maxwell. In a similar way Abraham-Föppl give ϵ as the general expression for the dimension of dielectric constant in terms of ϵ and $L^{-2}T^{2}\mu^{-1}$ for its dimensions in terms of μ.[24] Thus from the original establishment of the absolute systems of electric and magnetic units by Gauss and Weber, through their development by Maxwell, Föppl, M. Abraham and many others, there seems to have been no question raised, at least by a competent authority, as to the proper dimensions to be assigned to the various units in each given system.

The present controversy regarding dimensions apparently started with a paper by Rücker,[25] whose ideas were later developed more fully by Williams.[7] Rücker's point of view is shown sufficiently by the quotation from his paper given by Bridgman,[2]

> "In the calculation of the dimensions of physical quantities we not infrequently arrive at indeterminate equations in which two or more unknowns are involved. In such cases an assumption has to be made, and in general that selected is that one of the quantities is an abstract number. In other words, the dimensions of that quantity are suppressed.
>
> The dimensions of dependent units which are afterwards deduced from this assumption are evidently artificial, in the sense that they do not necessarily indicate their true relations to length, mass, and time. They may serve to test whether the two sides of an equation are correct, but they do not indicate the mechanical nature of the derived units to which they are assigned. On this account they are often unintelligible."

This quotation has been repeated in full because it embodies so perfectly the underlying philosophy of the school of writers that believes in the absolute character of dimensions. Rücker evidently looks upon length, mass and time as unique fundamental units, in terms of which all other units should be expressed. I hope, however, that the discussion in Part I of this paper has made it clear that there is nothing unique about either the number or the choice of the fundamental units. Rücker also believes that the dimensions of a *unit* indicate the intrinsic nature of a *physical quantity*. Thus he speaks of the "mechanical nature of the derived units," whereas the term "mechanical nature" can properly be applied only to the physical quantity itself. There can be little doubt that this failure to draw the distinction emphasized by H. Abraham[8] between the *dimensions of the unit*, which depend upon certain *arbitrarily adopted conventions*, and the intrinsic nature of the physical quantity itself, which is certainly not arbitrary, whether known or unknown, lies at the base of the fruitless controversies that have been waged in this field during the past half century. A perusal of modern texts and papers relating to electric and magnetic units shows clearly that the attempt on the part of certain subsequent writers to incorporate Rücker's philosophy into electromagnetic theory has resulted in a devastating variety of treatments, a portion of which are not even self-consistent. Some of these inconsistencies have been pointed out by the writer.[1] Subsequent criticism of certain of his remarks by Page and Adams[26] serves only to emphasize the present unfortunate state of affairs in this field. As a result of certain points raised in their paper, and in my private correspondence, particularly with members of the Committee on Units of the American Association of Physics Teachers, it seems necessary to consider in somewhat more detail the material presented in my first paper.[1] The general principles to be employed have been outlined in Part I of the present paper. Let us now apply them to electric and magnetic units.

It was pointed out in Part I that *every* equation defining a derived unit contains a factor of proportionality to which one may assign an arbitrary numerical magnitude *and* arbitrary dimensions, including *zero* dimension. In the c.g.s. mechanical system unit value and zero dimension are, in fact, systematically assigned to every such factor of proportionality, and by this means the number of arbitrary fundamental units and dimensions is held down to three, whereas otherwise the number would increase almost without limit. No one, not even Rücker, has objected to this procedure. When, however, one follows a precisely similar procedure in the case of the Coulomb equation, $F=aee'/r^2$[Eq. (10)], and ac-

[24] These expressions are given also in the *International Critical Tables*, Vol. I, p. 36. Recent criticism of them by Page and Adams (reference 26 ahead) appears to be based on a misconception of their meaning.

[25] A. W. Rücker, "On the Suppressed Dimensions of Physical Quantities," Phil. Mag. (5) **27**, 104 (1889).

[26] L. Page and N. I. Adams, Jr., "Some Common Misconceptions in the Theory of Electricity," Am. Phys. Teacher **3**, 51 (1935).

cordingly assigns unit magnitude and zero dimension to the factor of proportionality a, Rücker and his followers claim that the "true" dimensions of a have been "suppressed," with resulting false inferences. What is it now that distinguishes the factor of proportionality in this case from all other cases? This is a question that has been practically ignored in the literature, but that seems to lie at the very heart of the controversy.

As I understand the matter, Rücker would say that the constants of proportionality in equations such as (5) and (7) of Part I may obviously be taken as pure numbers, but that the a in Eq. (10) cannot be so treated. He would say that it is the reciprocal of the "dielectric constant of vacuum ϵ_0," and as such is a real physical magnitude and must have some dimension or dimensions, even though these are now unknown to us. It has been noted, however, in the discussion following Eq. (6), that there are certain universal constants, such as c, G, ϵ_0 and μ_0, that play a *double* role. Let us consider the following equations in which these four constants occur in an especially simple way:

$$l=ct, \qquad (15) \qquad\qquad F=Gmm'/r^2, \qquad (16)$$

$$F=\frac{1}{\epsilon_0}\frac{ee'}{r^2}, \qquad (17) \qquad\qquad F=\frac{1}{\mu_0}\frac{pp'}{r^2}, \qquad (18)$$

in which p, instead of the more usual symbol m, denotes magnetic pole, and m denotes mass.

In their *first* role each of the four constants represents some property of empty space. Thus c is the velocity of photons in space, G is the universal constant of gravitation, ϵ_0 is the dielectric constant of space, μ_0 is the permeability.[27] In this first role one must assume that the *dimensions* of each constant are to be derived by *assigning* dimensions to all other magnitudes that appear in the equation. Thus, in Eq. (15), the dimensions of c are LT^{-1}, if we choose to assign to l and t the dimensions L and T, respectively. Similarly the dimensions of G, in Eq. (16), are $M^{-1}L^3T^{-2}$, if we choose to assign the c.g.s. dimensions MLT^{-2} to F, M to m and m', and L to r. A similar treatment of Eqs. (17) and (18) requires that intrinsic dimensions be assigned also to charge (e) and pole strength (p). Let these dimensions be E and P respectively. Then, using the c.g.s. mechanical units, the dimensions of ϵ_0 are $M^{-1}L^{-3}T^2E^2$, and those of μ_0 are $M^{-1}L^{-3}T^2P^2$. This interpretation of Eqs. (15)–(18) thus requires *five* fundamental units.[28]

In their *second* role each of the four constants in Eqs. (15)–(18) is considered as a mere factor of proportionality. Now it is evidently highly desirable that the defining equation of any derived unit should be of universal validity; that is, independent of space and time. It is for just this reason that a constant connected with the properties of empty space is ideally suited for use as a factor of proportionality in such a defining equation, since such properties are, by assumption, invariant in space and time.

Let us therefore treat Eqs. (15)–(18) as defining equations for certain derived units. The simplest procedure, as usual, is to assign unit magnitude and zero dimension to each factor of

[27] At first sight it might appear that there is an essential distinction between G and the other three constants, in that, when the medium is changed from empty space to an actual dielectric, c, ϵ_0 and μ_0 change in value (to v, ϵ and μ) whereas G does not. This, however, represents a very superficial view of the matter. Thus if the force between *free* charges is alone considered, this does vary as the reciprocal of the dielectric constant of the medium. But the force between *total* charges (free plus bound) is quite as independent of the medium as is the force of gravitation. Similarly one should think of photons as being passed from atom to atom in a material, *always* with a speed c, the deviation of the refractive index from unity being due to a specific time relation involved in the absorption and re-emission of a photon by each atom.

[28] It may be thought that due to the known relations between electric and magnetic quantities, one is not free to choose both e and p as additional fundamental units. This, however, is not the case. In my first paper[1] I quoted the remark emphasized by Max Planck [*Theory of Electricity and Magnetism*, Eng. tr. by Brose (1932), p. 15] that in the general equation for the velocity of an electromagnetic wave in vacuum,

$$c=k/(\epsilon_0\mu_0)^{\frac{1}{2}}, \qquad (19)$$

two of the three constants k, ϵ_0 and μ_0 *must* be arbitrarily fixed in regard both to magnitude and dimensions. Planck here assumes that the c.g.s. mechanical system has already been adopted so that $c\sim 3\times 10^{10}$ cm·sec^{-1}, with dimensions LT^{-1}.

The constant k appears in a number of electromagnetic equations, such as Maxwell's third field equation,

$$\text{curl}\, H=(1/k)(4\pi i+\partial D/\partial t). \qquad (20)$$

If both charge and pole strength are adopted as additional fundamental units, with resulting dimensions of ϵ_0 and μ_0 as just given, then Eq. (19) is satisfied if we assume for k the dimensions $M^{-1}L^{-2}TEP$. Naturally, in measuring the magnetic field H produced by current density i, the simplest assumption is that k has unit magnitude and zero dimension. This is, in fact, the assumption made in the e.s. and e.m. systems, but it is by no means necessary. For instance in the Gaussian system $k=c$, with dimensions LT^{-1}.

proportionality. If this is done in Eq. (15) one obtains

$$l = t \qquad (15')$$

as an invariant relation holding for photons. This leads to a system of units in which space and time have the same dimension, and as noted in Part I, such a system is of particular convenience in the restricted theory of relativity.

A similar treatment of Eq. (16), yielding

$$F = mm'/r^2, \qquad (16')$$

leads to a new derived unit of force, which in Part I was called the gravitational unit of force. As noted in Part I, it is possible to do this, and at the same time retain the fundamental c.g.s. units of length, mass and time, if one treats the k in $F = kma$ [Eq. (7)] as an experimental constant, with dimensions $ML^{-3}T^2$. If, however, one adopts Eq. (16′) and simultaneously adopts

$$F = ma, \qquad (7')$$

there are two equations of condition among four quantities (force, mass, length and time), and consequently only two of the four units can be taken as fundamental.

In the general theory of relativity it is customary to adopt simultaneously Eqs. (15′), (16′) and (7′). There are now three equations of condition between the same four quantities, so that only one of the four units is fundamental. Furthermore, it is customary to adopt *length* as the single dimension, with the centimeter as the unit. Then it is easy to show that time and mass each has the dimension of length, with the new units[29] 3.335×10^{-11} sec and 1.349×10^{28} g.

This new system of units is sufficient for all problems in mechanics. When, however, electric and magnetic quantities are involved, it is necessary either to increase the number of fundamental units, *or* to adopt additional defining equations, which serve to prevent such an increase. It is the latter procedure that yields the so-called absolute systems of electric and magnetic units.[30] Thus in the Gaussian system one adopts the defining equations

$$F = ee'/r^2 \quad (17') \qquad F = pp'/r^2, \quad (18')$$

obtained from Eqs. (17) and (18) by assigning unit value and zero dimension to ϵ_0 and μ_0.

In the Gaussian system the mechanical units of the c.g.s. system are retained, so that there are three fundamental units in all. If, however, Eqs. (17′) and (18′) are combined with Eqs. (7′), (15′) and (16′), one obtains a complete system of units (except for thermal units) in which only *one* unit is fundamental. This is the customary procedure in the general theory of relativity, when that theory is extended to include electric and magnetic relations.[31]

In this last system of dimensions the five important units, length, mass, time, electric charge and magnetic pole all have the same dimension. Of these five quantities electric charge has the most obvious natural unit, namely, the charge of an electron or proton. Hence it appears reasonable to adopt this charge as the single arbitrary unit (with intrinsic dimension E), rather than the centimeter (with intrinsic dimension L) as is done by Eddington[31] and Tolman.[29] The new system of units that results from this assumption is outlined in Table I. In order to evaluate the units of the new system, in terms of the present c.g.s. units, it is necessary to adopt a value of e (electron charge) as well as of c, G, ϵ_0 and μ_0, in terms of such units. The adopted values appear in the first five lines of Table I. Each unit with dimension E in this table has in the Eddington-Tolman system dimension L and a magnitude,

[29] R. C. Tolman, *Relativity, Thermodynamics and Cosmology* (Oxford, 1934), pp. 201–202.

[30] There are three such systems commonly found in the literature and my first paper[1] was devoted mainly to a discussion of them. As noted there, these three systems, the electrostatic, the electromagnetic, and the Gaussian, correspond, respectively, to the assignment of unit value and zero dimension, in Eq. (19), to k and ϵ_0, k and μ_0, and ϵ_0 and μ_0. A fourth possible absolute system, in which ϵ_0 and μ_0 are each given the dimensions $L^{-1}T$ and consequently k has zero dimension, was suggested first by G. F. Fitzgerald [Phil. Mag. (5) **27**, 323 (1889)], and has recently been discussed in detail by A. E. Kennelly [Proc. Nat. Acad. Sci. **17**, 147 (1931)] with no reference, however, to Fitzgerald's earlier suggestion. This new system has the advantage of the Gaussian system in that corresponding electric and magnetic units have the same dimensions, and also the advantage of the e.s. and e.m. systems in that k is dimensionless. Kennelly sets $k = 1$, so that, from Eq. (19), both ϵ_0 and μ_0 equal $1/c$. Page (2nd reference of footnote 37 ahead) points out some objections to this system, but it seems to the writer worthy of serious consideration.

[31] As an example, A. S. Eddington, *The Mathematical Theory of Relativity* (Cambridge, 1924), p. 185, writes $\gamma = 1 - 2m/r + 4\pi e^2/r^2$, an equation which evidently requires that mass (m), length (r) and charge (e), all have the same dimension. This point is discussed briefly by Eddington in his footnote, p. 87.

TABLE I.

Unit	Dimensions	Value in c.g.s. Units
Velocity c	0	2.99774×10^{10} cm·sec^{-1}
Constant of gravitation G	0	6.670×10^{-8} g^{-1}·cm^{3}·sec^{-1}
Dielectric constant ϵ_0	0	1 (e.s. units)
Permeability μ_0	0	1 (e.m. units)
Electric charge	E	4.768×10^{-10} e.s.u.
Magnetic pole	E	4.768×10^{-10} e.m.u.
Length	E	$(1.370\ldots)\times10^{-34}$ cm
Mass	E	$(1.846\ldots)\times10^{-6}$ g
Time	E	$(4.571\ldots)\times10^{-45}$ sec
Acceleration	E^{-1}	$(6.558\ldots)\times10^{54}$ cm·sec^{-2}
Force	0	$(1.2107\ldots)\times10^{49}$ dynes
Energy	E	$(1.659\ldots)\times10^{15}$ ergs
Action	E^2	$(7.5836\ldots)\times10^{-30}$ erg·sec

in c.g.s. units, given by the ratio of the magnitude stated in Table I to $(1.370\ .\ .\ .\ )\times10^{-34}$ cm.

Before leaving this subject it should again be noted that the choice of a system of units is a matter primarily of convenience. If Eqs. (7), (15), (16), (17) and (18) are of common occurrence in the problem treated, it is *convenient* to reduce these equations to their simplest form by the elimination of each of the factors of proportionality. One thus obtains the five defining equations (7′), (15′), (16′), (17′), (18′), which involve six quantities, so that only one of the six units can now be chosen arbitrarily. The resulting system of units is a real convenience in the general theory of relativity and accordingly is in common use in that subject. But in ordinary classical physics Eqs. (15′) and (16′) are rarely needed. Hence it is more convenient to adopt, in mechanical problems, merely Eq. (7′). One thus gets a system of mechanical units that contains three fundamental units. The c.g.s. system is one example. When any system of mechanical units is extended to include electric and magnetic units, it is again a matter of convenience whether one adopts defining equations such as (17′) and (18′), and thus prevents an increase in the number of necessary fundamental units, or whether one or two additional fundamental units are postulated.

Mention has been made of the diversity of treatment of electric and magnetic quantities found in current literature. This diversity centers chiefly on the nature and dimensions of ϵ_0 and μ_0, and it is to my remarks concerning these quantities that Page and Adams[26] take particular exception. They quote Maxwell[22] (Vol. I, p. 55) and Abraham-Föppl[23] (Vol. I, p. 144) as defining dielectric constant as the ratio of the capacitance of a condenser with the given dielectric, to its capacitance with vacuum as the dielectric. Such a definition obviously gives to ϵ an unchanging numerical value, and zero dimension, in every possible system of units. On the other hand, as already noted, Maxwell[22] (Vol. II, p. 267) assigns zero dimension to the dielectric constant in the e.s. system and T^2L^{-2} dimensions in the e.m. system, and on p. 268 he writes, "In the electrostatic system the specific dielectric inductive capacity[32] of air is assumed equal to unity. This quantity is therefore represented by $1/v^2$ in the electromagnetic system." [His v is our $c\sim3\times10^{10}$ cm·sec^{-1}.] Precisely similar statements occur in Abraham-Föppl[23] (Vol. I, pp. 257–262). There thus exists an apparent discrepancy in the treatment of ϵ and μ in each of these two authoritative texts, a discrepancy that has been repeated in numerous subsequent texts.

I find it difficult to give any adequate account of the origin and present status of this discrepancy without going into prohibitively long details. For that reason it seems best to give merely the following analogy which seems very illuminating. I narrate the following series of events as though it actually had occurred (and it might have occurred) although it is, of course, purely hypothetical:

"The name *refractive index* of a medium was given originally to the dimensionless ratio sin r/sin i [i.e., the reciprocal of our present refractive index]. Later it was found that this was identical numerically with the ratio v/v_0, where v is the velocity of light in the medium, and v_0 (or c) the velocity in empty space. Moreover, in the system of units and dimensions adopted at about that time v_0 was given unit value, and velocity in general was dimensionless. Hence the ratio v/v_0, which represents the *relative velocity* of light in the medium, was identical in magnitude and dimension with the *absolute velocity* v. For that reason the qualifying adjectives *relative* and *absolute* were dropped and one spoke only of the *velocity* of light in the medium. Furthermore, the original designation *refractive index* of

[32] That dielectric constant and specific inductive capacity were used as synonymous names by the earliest writers is clear from Maxwell's treatise,[22] where no less than *six* different names are used for this one quantity. They are specific inductive capacity (Faraday's original designation, and used by Maxwell, Vol. I, p. 55), dielectric constant (I, p. 55), dielectric capacity (II, p. 252), dielectric inductive capacity (II, p. 257), specific dielectric inductive capacity (II, p. 268), and specific capacity for electrostatic induction (II, p. 433).

the medium was also used as synonymous with the name *velocity of light* in the medium.

This caused no trouble until somewhat later when an additional system of units and dimensions, the c.g.s. system, was incorporated into scientific work. In this new system v_0 had a different numerical value and had dimensions. Hence in this system v and v/v_0 were no longer identical. But, quite illogically, the original synonymous names *refractive index* of a medium, and *velocity of light* in a medium, were now still applied to v, regardless of the system of units used. Thus *refractive index*, originally defined as a simple ratio, now had varying numerical values and dimensions, depending on the system of units. The resulting confusion was finally eliminated by an agreement to use the names *refractive index* or *relative velocity* for the ratio $v/v_0 = \sin r/\sin i$, and *velocity* or *absolute velocity* for v."

The analogy breaks down at only one point. The terms *specific inductive capacity* and *dielectric constant* originally were identical in meaning, whereas in my analogy the terms *refractive index* and *velocity* meant intrinsically different things, just as they do in actual science, and merely happened to agree, numerically and dimensionally, in a certain adopted system of units. In my first article[1] I followed the *International Critical Tables* in using the names *specific inductive capacity* for $\kappa = \epsilon/\epsilon_0$ and *dielectric constant* for ϵ, but because of the original identical meaning of these terms it doubtless would be better to use the names *relative dielectric constant* and *absolute dielectric constant*,[33] which are self-explanatory and cannot possibly be confused. This agrees essentially with recent international action.[34] As this action shows, it is now recognized by all authorities that it is necessary to consider two different sorts of electric quantities (and similarly two different magnetic quantities), one of which is a pure number, and the other of which has a magnitude and dimensions dependent upon the system of units adopted. Further light on this subject comes from a consideration of the two different treatments of electric and magnetic quantities now to be found in the literature.

In my first paper[1] I followed the treatment of Maxwell,[22] Abraham-Föppl,[23] Planck,[28] and practically all other authorities, both past and present.[35] In that treatment the dielectric constant ϵ is defined as the ratio of D to E, regardless of the system of units used, and the permeability μ always as the ratio of B to H. These two quantities, ϵ and μ, then have different magnitudes and dimensions in different systems of units. More recently, however, a few authors, including Abraham-Becker,[36] Page and Adams,[37] and Webster,[14] have advocated a second treatment that in essence confines the meaning of specific inductive capacity *or* dielectric constant to that of a pure ratio, regardless of the system of units used. In its most general form this treatment is as follows. In place of the defining equations of the first treatment,

$$F = \frac{1}{\epsilon}\frac{ee'}{r^2}, \quad (21) \qquad F = \frac{1}{\mu}\frac{pp'}{r^2}, \quad (22)$$

one writes

$$F = \frac{a}{\epsilon}\frac{ee'}{r^2}, \quad (23) \qquad F = \frac{b}{\mu}\frac{pp'}{r^2}. \quad (24)$$

Eqs. (21) and (22) are interpreted to apply to any system of units. As we have seen, it is then desirable to define *four* quantities, which in my nomenclature are ϵ, $\kappa(=\epsilon/\epsilon_0)$, μ, and $\kappa'(=\mu/\mu_0)$. In the *second* treatment, based on Eqs. (23) and (24), it is still necessary to consider four quantities, but these quantities are now a, b, ϵ and μ. Webster[14] has called a the *constant of electrostatics*, as noted in Part I. Similarly b may be

[33] These names are used in the excellent Müller-Pouillet, *Lehrbuch der Physik*, ed. 11, Vol. 4, Part 1, pp. 43, 115. It is possible that the distinction between a *relative* and *absolute* dielectric constant (and permeability) was made first by Sir Oliver Lodge who includes in a long letter written in 1895 to the B. A. Committee[21] (p. 525) the remarks: "The inductivity (μ), or absolute permeability of a medium at any point, under specified circumstances, is the ratio of B to H at that point, and under those circumstances. The relative inductivity of a substance as compared with that of empty space (μ/μ_0) may be called simply its 'permeability,' as at present, and is a mere number. Its electrical analog is specific inductive capacity (κ/κ_0) as contrasted with absolute electric inductivity (κ)."

[34] This action is given in the *Reports on Symbols, Units and Nomenclature* [S.U.N. Reports] (Cambridge Univ. Press, 1935), and was approved by the International Union of Pure and Applied Physics at London, Oct. 5, 1934. No wholly uniform nomenclature is used in these reports, with their numerous appendices, but that most commonly used is *specific* or *relative permeability* ($\mu = \mu_1/\mu_0$) and *absolute permeability* μ_1. These reports are mentioned later in this paper. So far as the symbols are concerned, those used by H. Abraham[8] ($\mu_r = \mu/\mu_0$) would have been preferable, since the r in μ_r suggests *relative* permeability.

[35] It is that treatment which has received some criticism.[26]

[36] M. Abraham (rev. by R. Becker), *Classical Theory of Electricity and Magnetism*, tr. of 8th Ger. ed. (1932), pp. 152–153.

[37] L. Page and N. I. Adams, Jr., *Principles of Electricity* (1931); also L. Page, "Electromagnetic Equations and Systems of Units," Physics **2**, 289 (1932).

called the *constant of magnetostatics*. The quantities ϵ and μ now represent pure ratios; that is, the relative dielectric constant ϵ/ϵ_0 and the relative permeability μ/μ_0 of the first treatment. They are dimensionless, and of unit value in vacuum, in all systems of units. The constants a and b are then merely proportionality constants, introduced into Eqs. (23) and (24) to satisfy the numerical magnitudes and dimensions of the two sides of each equation. Thus in the e.s. system a is unity and dimensionless; $b=c^2$, with dimensions L^2T^{-2}. In the e.m. system b is unity and dimensionless; $a=c^2$, with dimensions L^2T^{-2}. In the Gaussian system both a and b are unity and dimensionless.

By this method of treatment our Eq. (19), for the velocity of an electromagnetic wave in vacuum, becomes

$$c=k(ab/\epsilon_0\mu_0)^{\frac{1}{2}}=k(ab)^{\frac{1}{2}}, \tag{25}$$

since ϵ_0 and μ_0 are now by definition always unity and dimensionless. Similarly the velocity in a medium of (relative) dielectric constant ϵ and permeability μ is given by

$$v=k(ab/\epsilon\mu)^{\frac{1}{2}}. \tag{26}$$

I have never seen Eqs. (25) and (26) in print, even in those texts that advocate this second method of treatment. In fact practically every author who discusses electromagnetic waves gives Eq. (19) as I have written it, or the still simpler form

$$c=1/(\epsilon_0\mu_0)^{\frac{1}{2}}, \tag{27}$$

a form that corresponds to the arbitrary assumption $k=1$ (and dimensionless) in Eq. (20) and in similar equations. When $k=1$ in Eq. (20) it is usually said that "the units on both sides of the equation are in the same system."[38] This is equivalent to the assumption that the magnetic field due to current density i *must* be given by the equation

$$\text{curl } H=4\pi i. \tag{28}$$

It is obvious, however, that curl H is, experimentally, merely *proportional* to i, and 4π already represents an arbitrarily chosen factor of proportionality. The $4\pi/k$ of Eq. (20) is merely one way of writing the corresponding *general* factor of proportionality. It happens that in the e.s. and e.m. systems k is unity and dimensionless, but in the Gaussian system it is necessarily c, with dimensions LT^{-1}, as shown by Eq. (19), since the Gaussian system is defined by assuming unit value and zero dimension for *both* ϵ_0 and μ_0. This general point of view has been emphasized by H. Abraham.[8]

My present chief objection to the adoption of Eqs. (23) and (24) is that they represent no simplification of the more usual treatment, and in fact *four* different quantities, such as a, b, ϵ and μ, necessarily enter into *any* possible treatment. Any apparent simplification of the second treatment results only when one fails to carry the constants a and b through all equations. This failure, in turn, can lead easily to error and misunderstandings. Provided an author explicitly states his assumptions regarding units and dimensions, any one of a number of possible treatments of electric and magnetic quantities appears equally suitable.

Before leaving this subject mention should be made of the system of units first proposed by Giorgi.[39] Giorgi has attempted to avoid the annoying numerical relations (10^8, 10^{-1} etc.) now existing between the *practical* volt-ohm-ampere system and the absolute electromagnetic system, which Maxwell and Jenkin[21] based on the centimeter-gram-second mechanical units. He noted that one could retain the volt-ohm-ampere units, and also reduce to unity (from 10^8, 10^{-1}, etc.) most of the important factors of proportionality connecting electrical and mechanical units, if one chose as new fundamental mechanical units the kilogram (K), meter (M) and second (S). Giorgi

[38] The idea that k *must* be unity (and dimensionless) in any consistent set of units, and that as a consequence the Gaussian system (and any number of similar possible systems) is a "mixed" system, is one of the most common errors in the literature. A correct formulation of Eq. (19) is given in the S.U.N. Reports[34] (p. 11), and also by F. Zerner in the voluminous and authoritative Geiger and Scheel *Handbuch der Physik*, Vol. 12, p. 78; but in this *same Handbuch* (Vol. 2, p. 29) J. Wallot writes "Even to-day it is customary to assume dielectric constant and permeability as without dimensions and so to ascribe to the necessary unit equations two arbitrary quantities, which contradicts the equation of light velocity $c=1/(\epsilon\mu)^{\frac{1}{2}}$." It may be noted that this remark is part of a general philosophical discussion of units and dimensions by Wallot, who is one of the few recent writers that have raised objections to Bridgman's theory of dimensions.

[39] For a recent full account of the Giorgi system see G. A. Campbell, "A Definitive System of Units," Bull. Nat. Res. Council **93**, 48–79 (1933). The *definitive system* is a slight modification of Giorgi's proposed system. This system is strongly advocated also by Crew[20] (pp. 310–316).

also assumed a *four*-fundamental-unit system, with the present *international ohm* (Ω) as the fourth fundamental unit. Hence this is often called the M.K.S.Ω. system.

It may be noted, in agreement with Kennelly,[40] that all of the important numerical advantages of the Giorgi system would be retained if one should use the *absolute* ohm, and thus adopt a *three*-fundamental-unit system. To achieve this, it is necessary merely to *assign* to μ_0 the value 10^{-7} and zero dimension. It would certainly be unfortunate, at this date, to adopt an artificial unit like the *international* ohm, which belongs to class one as discussed in Part I of this paper, and such action would be in direct contradiction to the latest international action,[41] by which the units of the *absolute* electromagnetic system are adopted in principle as the primary standards, and the international units are again recognized as merely laboratory copies, whose specifications are to be revised, when necessary, in order to make them conform more closely to the absolute units.

I conclude this paper with a very brief mention of certain recent international actions. To give any adequate discussion would require an entire paper in itself, but one particular action is so directly related to the subject matter of this paper, and so disconcerting, that a brief comment seems unavoidable.

There are two international committees, the International Electrotechnical Commission (I.E.C.), which was inaugurated in 1904 at the International Electrical Congress in St. Louis, and the Committee on Symbols, Units and Nomenclature (S.U.N. Committee) of the International Union of Pure and Applied Physics (I.P.U.), which was appointed by that body in 1931. Section B of the I.E.C. deals with Electric and Magnetic Magnitudes and Units (E.M.M.U.) under the chairmanship of Professor A. E. Kennelly. Sir Richard Glazebrook is chairman of the S.U.N. committee. This committee held a meeting at Paris, 1932, for discussions of the subject,[41] and an official action was taken at the London, 1934, meeting of the I.P.U.[34] A meeting of the American section of the I.P.U. was held in Chicago, 1933, at which papers on this subject were presented.[42] The I.E.C. met at Oslo in 1930 and at Paris in 1932. All of the actions of these bodies are given in the S.U.N. Reports.[34] The actions taken by the I.E.C. at Oslo, 1930, and confirmed at Paris, 1932, have been reported by Kennelly in this journal and elsewhere.[43]

Both the S.U.N. Committee and the I.E.C. agreed to recommend *Gauss* as the name for the unit of magnetic induction or flux density B, and *Oersted* as the name of the unit of field strength H. These are *electromagnetic* units. The names Gauss and Oersted were officially accepted by the I.P.U., at London, 1934, and this constitutes the only *official* action of interest to this paper. However, the S.U.N. Reports[34] include, for the information of the I.P.U., the resolutions adopted by the I.E.C. at Oslo, and confirmed at Paris, from which I quote as follows:

"That the formula $B=\mu_0 H$ represents the modern concepts of the physical relations for magnetic conditions *in vacuum*, it being understood that in this expression μ_0 possesses physical dimensions. In the case of magnetic substances the above formula becomes $B=\mu_1 H$ in which μ_1 has the same dimensions as μ_0. It follows that the specific or relative permeability of a magnetic substance is a number equal to μ_1/μ_0."

The statement as to the physical dimensions of μ_0 is meaningless unless the system of units to which it applies is specified. The further statements of the I.E.C.[44] show, however, that the *classical electromagnetic* system and various numerical modifications of it are meant. The *numerical* value of μ_0 varies in these systems, but in all of them, as in the original Maxwell system where $\mu_0=1$, this magnitude is, *by definition, without dimensions*. The discussions of the I.E.C. centered on the question as to whether the physi-

[40] A. E. Kennelly, J. Eng. Ed. **19**, 229–275 (1928), p. 264. This is the most complete account I have seen of the various systems of electrical units, treated from the practical standpoint. The paper contains also a valuable bibliography of 75 references. The excellent report by Kennelly, Bull. Nat. Res. Council **93**, 94 (1933), also should be mentioned.

[41] See Nature **132**, 975 (1933) for a brief statement of this latest action, and *Congrés International d'Electricité* (Paris, 1932), Vol. III, Sec. 2, for detailed papers on every phase of this subject.

[42] *Systems of Electrical and Magnetic Units*, Bull. Nat. Res. Council **93** (1933); papers by R. T. Glazebrook, H. Abraham, L. Page, G. A. Campbell, H. L. Curtis, and A. E. Kennelly. The beautiful report by Abraham has been mentioned (reference 8), as well as the papers by Campbell (reference 39) and Kennelly (reference 40).

[43] A. E. Kennelly, Am. Phys. Teacher **3**, 89 (1935); Proc. Nat. Acad. Sci. **19**, 144 (1933).

[44] See reference 34, Appendix V.

cal magnitudes B and H were of the same character or not. In spite of H. Abraham's clear and convincing reports[8, 34] to the contrary, the I.E.C. decided that B and H had different physical characters. I do not agree with this decision, but *if* the decision were correct it would be proper and convenient to use different names for the units of B and H. Similarly, in the c.g.s. system *dyne-cm* and *erg* are the respective names of the units of torque and of work, since everyone agrees that these are physical quantities of different natures. But in the c.g.s. system the units of work and torque have the *same dimensions*, and the intrinsic character of a physical quantity has no necessary connection with the *dimensions* assigned to the *unit* of that quantity. This is the central theme of the present paper, and of the work of Bridgman,[2] Planck,[28] H. Abraham[8] and other writers. The I.E.C. seems to favor the theory of the absolute character of dimensions. Having voted that B and H were of different physical character, the I.E.C. apparently assumed, without further debate, that they *therefore necessarily* had different dimensions; in other words, that their ratio possessed physical dimensions. If the entire scientific world could only realize clearly that the character of a physical quantity is a matter of philosophy, while the assigned dimensions of its unit are a matter of mere convention having only arithmetic significance, unending and utterly fruitless controversies would be avoided. Meanwhile one can only hope that the point of view of the I.E.C. will *not* be accepted by physical scientists.

Models of Thermodynamic Surfaces

FRANK L. VERWIEBE, *Department of Physical Science, Eastern Illinois State Teachers College*

BEGINNERS as well as many advanced students often find it difficult to visualize the $P-V-T$ relations for simple substances. The usual set of isothermal curves for such substances as carbon dioxide fail to give a complete picture of these relations, and they seldom include the transitions to the solid state. The $P-V-T$ curves for ordinary water rarely are given in the textbooks although they are of particular interest because of the anomalous behavior of water. On the other hand, all of these relations can be shown clearly by means of models which are not difficult to construct.

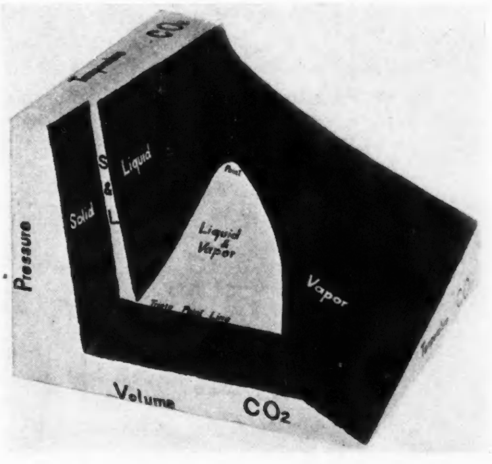

FIG. 1. Photograph of model for carbon dioxide.

The models shown in Figs. 1 and 2 are of course dimensionally quite diagrammatic; the scale of some of the transitions had to be exaggerated arbitrarily to make the volume changes visible at all. They are nevertheless very useful in assisting the student to visualize the general behavior. The families of curves shown in Figs. 3 and 4 are easily traced on the models themselves and are readily explained when the models are before the student's eyes. They show in a clear-cut fashion some of the more elementary but interesting $P-V-T$ characteristics which Bridgman has discussed exhaustively[1, 2] but which are usually not mentioned in the elementary textbooks.

[1] P. W. Bridgman, *The Physics of High Pressure* (Macmillan, 1931), Chaps. V, VII, VIII. This book also contains a comprehensive bibliography.

[2] P. W. Bridgman, "Theoretically Interesting Aspects of High Pressure Phenomena," Rev. Mod. Phys. **7**, 1 (1935).

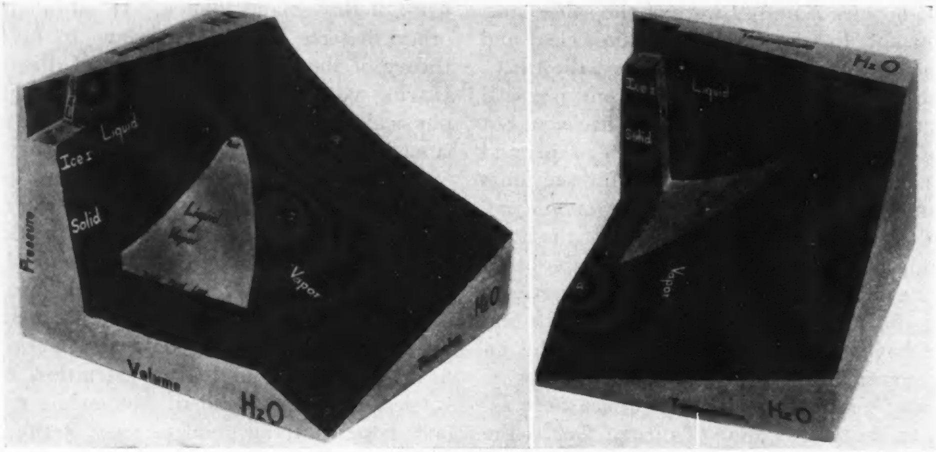

FIG. 2. Two views of model for water, including two of the ice phases, I and II.

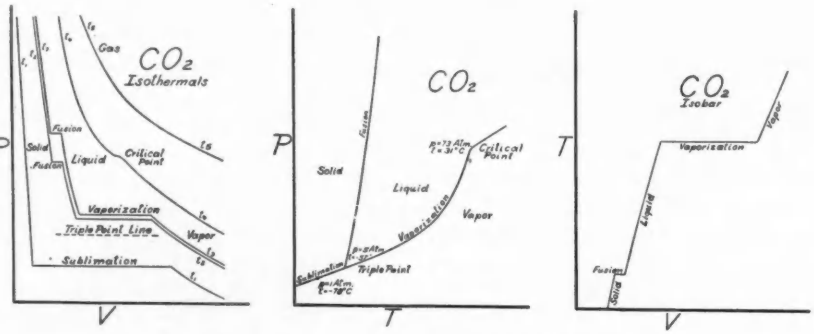

FIG. 3. $P-V$, $P-T$, and $T-V$ curves for carbon dioxide.

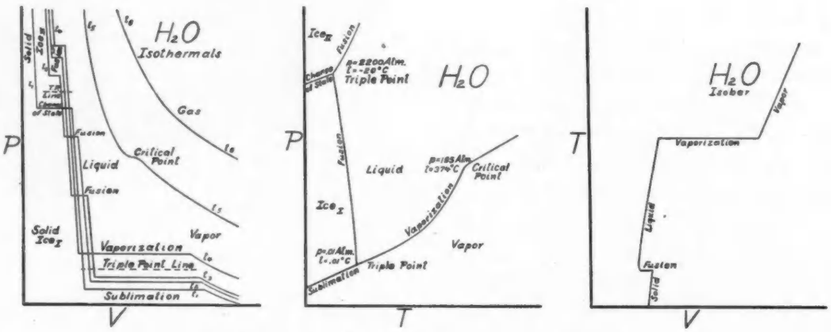

FIG. 4. $P-V$, $P-T$, and $T-V$ curves for water.

These surfaces first were modeled in clay, and then negative plaster casts were made from the clay models, and positives cast from the negatives. A little paint applied in different colors makes the transitions stand out more clearly and aids in preserving the surfaces.

Water is one of the few substances that shows a diminution of volume during fusion; the others

are cast iron, gallium, and bismuth, the latter two of which have been examined along with water in the physicist's laboratory. This diminution of volume is associated thermodynamically with a negative $(\partial p/\partial t)_v$, the relation that the melting temperature falls as the pressure is increased at constant volume. Until recently water was the only one of these substances known to revert (above 2200 kg/cm^2 of pressure) to the more common type of behavior as exemplified by carbon dioxide, for which $(\partial p/\partial t)_v$ is positive. Last year, however, Bridgman[3] reported finding a second state of solid bismuth (at about 25,000 kg/cm^2) which is denser than the liquid, and which therefore will have a melting curve with a positive slope.

Of the six known forms of ice only Ice$_{\text{I}}$ is abnormal. Fig. 2 shows the transition from Ice$_{\text{I}}$ to Ice$_{\text{II}}$ and the melting curve between water and Ice$_{\text{II}}$, with its positive slope. Tammann[4] states that there is a change in volume of approximately 20 percent in going from Ice$_{\text{II}}$ to Ice$_{\text{I}}$ as compared with the 8-percent change for Ice$_{\text{I}}$ to water; the change is of course an increase in the first case as compared with the decrease in the second. These changes are clearly shown on the model. The transitions to still higher forms of ice may be readily indicated by extrapolation, as may also the conditions under which water will exist as ice at ordinary room temperatures.

It is also interesting to note that, according to Bridgman,[5] any gas very probably can be condensed directly into a crystalline phase by the application of sufficient pressure at any temperature above the critical temperature.

All substances so far tested show $P-T$ melting curves that are concave toward the P axis. As to the ultimate behavior of the melting curve four theories have been advanced: a critical point, as in the case of liquid-vapor; a maximum temperature (Tammann); an asymptotic temperature (Schames); and an indefinite rise (Bridgman).[6] The first two have not been realized in the experimental pressure range, and the remaining two depend on extrapolation; hence the problem does not have a definite answer at the present time.

The $P-T$ graphs of Figs. 3 and 4, it may be worth noting, are not isovolumic curves throughout their ranges. Rather, they are projections of the more interesting isovolumic sections of the $P-V-T$ surfaces on $P-T$ planes. Each continuous curve represents a $P-T$ relation at constant volume, but the magnitude of that volume differs in general for each of the various curves constituting a $P-T$ graph. In a $P-T$ plane the projection of the triple point "line" will be a triple "point," which is strictly speaking a point only in terms of P and T, since a given mass has a wide latitude of volume values at that "point."

[3] P. W. Bridgman, Phys. Rev. **45**, 844 (1934).
[4] Reference 1, p. 242.
[5] Reference 1, p. 207.
[6] P. W. Bridgman, Phys. Rev. **46**, 930 (1934).

The A. A. P. T. Book on Demonstration Experiments

The receipt of numerous contributions to the A.A.P.T. book on demonstration experiments indicates a real interest in this cooperative undertaking of the Association. The editors of the book desire to receive suggestions from many more members now, so that the compilation can be completed without delay. Every physics teacher doubtless has several lecture experiments which he considers especially valuable and which he should be willing to share with others through the medium of this manual by sending short descriptions to the editor. A single paragraph and, if necessary, a free-hand line drawing usually will be adequate. Information is particularly desired with regard to modifications ot apparatus or of methods of presenting experiments. Address communications to Dr. Richard M. Sutton, Haverford College, Haverford, Pennsylvania.

Professor K. K. Smith
1887–1935

TO have known K. K. Smith ever since the day he entered Northwestern University, as a freshman, from Garrett, Indiana, in the autumn of 1906 has been to me a rare privilege. In the laboratory, he was a man of few words; but he early discovered himself as a student of the type whose opinion is to be respected when he *does* speak.

By 1910, he had completed his work for the bachelor's degree on the classical course, and immediately set out for Princeton in order to join that group of brilliant students (Davisson, the Comptons, *et al.*) with whom O. W. Richardson and E. P. Adams had surrounded themselves.

His first independent research was a quantitative investigation of the negative thermionic emission from tungsten, over a large temperature range, in a very high vacuum. The result was the establishment of the well-known emission formula of Richardson, $i=aT^{1/2}e^{-b/T}$, over an enormous range of validity, the emission extending from 10^{-13} amp. up to 1 amp.

Before leaving the Palmer Laboratory, where he took his doctor's degree in 1915, he made a series of measurements (important in the theory), on the Corbino effect, comparing the Corbino coefficient c with the Hall constant R/ρ, for a considerable number of substances. This work he later (1929) greatly improved and extended, with H. M. O'Bryan, at Northwestern University, where he had accepted an assistant-professorship in 1915 and an associate-professorship in 1921. The result of their joint work was a verification of the criterion, $c=R/\rho$.

Jointly with another student, P. W. Bigler, Smith used the thermionic current to determine the rapid changes of temperature which take place in an incandescent filament. For this purpose he employed a double high frequency oscillograph, and incidentally obtained the specific heat of tungsten at a temperature of over 2400°K. A little later he and Dr. Bockstahler described "An Improved Method of Measuring the Specific Heat of Metals at High Temperature" in which they used thermionic currents more accurately to determine the atomic heat of an incandescent metal.

As a teacher of undergraduates, "K. K." as he was familiarly known among his friends, directed his efforts mainly along the line of mechanics for second-year students and electricity and magnetism for third-year men; but the major portion of his energy was devoted to two graduate courses, one on the Mechanics of Rigid and Fluid Bodies, the other on Alternating Currents and Electric Waves.

Robust in mind and body, Smith had great facility in acquiring and mastering new ideas. This ability, combined with his gentle straightforwardness and with the fact that he never "passed the buck," made him always in demand for the work of journal meetings, faculty committees, and various science clubs to which he gave generously of both time and energy. The last two papers which he prepared were one on "Conduction in a Magnetic Field," to have been presented to the Chaos Club of Chicago on October 19, and one on "Physics and the Premedical Student," which was read, by a friend, before the American Association of Medical Schools at Toronto on October 28, 1935. These two addresses were, however, a small part of his unfinished work. He had a profound interest in the future of the American Association of Physics Teachers and was the leading man in the establishment of the Chicago Chapter. Truth was his major interest; and I therefore appreciate an opportunity to place a small wreath upon the untimely grave of this fearless spirit and helpful personality, a sacrifice to untoward circumstance.

HENRY CREW

I labor much less to catch the suffrages of the public than to obtain that inward approval which has always been the sweetest reward of my efforts.—From a letter written by Fresnel to Thomas Young in 1824.

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

An Improved Apparatus for the Determination of Joule's Equivalent by the Electrical Method

J. H. McLeod, *Harvard University**

THE apparatus illustrated in Fig. 1 was designed to enable the average student to determine Joule's equivalent with considerable precision. Water under constant pressure flows through the vacuum flask from left to right. The inlet and outlet temperatures are measured by thermometers graduated in 0.1° divisions. The corks that support the thermometers are placed far enough up on them to be well above any temperature reading that might be made. Electrical energy is supplied to the resistance coil through insulated wires inside a glass tube and is measured by an ammeter and a voltmeter in the usual manner. The current is regulated to a constant value by a variable rheostat.

The most important feature of the apparatus is the coil of tubing attached to the outlet pipe. It consists of about 18 in. of 3/16-in. copper tubing. Its purpose is to eliminate sudden fluctuations of the temperature of the outflowing water. In an experiment when no copper coil was used the temperature of the outlet was found to fluctuate as much as one degree. Evidently the warm water around the heater formed convection currents; sometimes this water flowed directly into the outlet and at other times mixed with the surrounding water before it entered the outlet, thus giving a fluctuating temperature. But when the water had to flow through a coil of copper tubing before emerging from the vacuum flask no fluctuation of the thermometer could be detected even with a magnifying glass.

The copper tubing should be placed as near the top of the flask as possible, with the intake end just below the rubber stopper. A piece of rubber tubing is convenient for joining the other end to the glass outlet tube. The spout on the glass

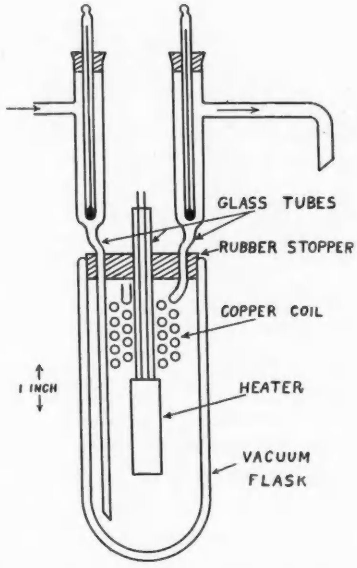

Fig. 1. Apparatus for determining Joule's equivalent.

outlet tube should be made large in diameter so that the flow will take place along the bottom only; this insures a constant level for the outflowing water.

Two different kinds of heaters were tried. One was a cartridge-type heater to which a glass tube for carrying the electrical leads was cemented; it consumed about 100 watts at 110 volts. The other was a "knife blade" heater taking about 250 watts; a glass tube, which has a low heat conductivity, was substituted for the usual metal handle. The "knife blade" heater proved to be superior; it reached equilibrium in a shorter time and the larger power consumption reduced errors considerably.

The following is a typical set of data:

* Now at Research Laboratory, Eastman Kodak Company, Rochester, N. Y.

		Estimated error	Percentage error
Current I	2.00 amp.	0.005	0.3
Voltage E	102.1 volts (av. of several readings)	0.3	0.3
Time T	300 sec.	0.5	0.2
Mass of water M collected in time T	1348 g	1.0	0.1
Temperature difference θ	10.86°C	0.02	0.2
	Total error		1.1

Joule's equivalent, $J = IET/M\theta = 4.18 \pm .04$ j/cal.

A class of first-year students at Harvard University obtained the values: 4.18, 4.26, 4.20, 4.18, 4.19 j/cal.

It is with pleasure that I acknowledge the assistance of Mr. S. Lanza, who assembled the apparatus.

A Lantern Slide Color Mixer

JOHN J. HEILEMANN, *Randal Morgan Laboratory of Physics, University of Pennsylvania*

WHEN three beams of white light are colored by interposing in their paths filters such as are used in three-color photography, white light will be reflected from a white screen which they illuminate simultaneously. The "purity" of the white thus produced depends upon the relative intensities of the colored components. Three-spot color mixers are commercially available; they are essentially three projectors using a single source, of else three separate projectors.

A simple arrangement which demonstrates the principle may be made by using a projection lantern, a lantern slide, three small pieces of red, green and blue gelatin filters and three mirrors. Wratten filters 29, 61 and 47 are satisfactory for this purpose. The slide (Fig. 1) consists of a card containing three circular holes covered by the gelatin filters and bound in the usual way between cover glasses. Fig. 2 shows how the slide is used. The three mirrors are placed in the paths of the divergent beams, and are set so as to cause the spots to overlap.

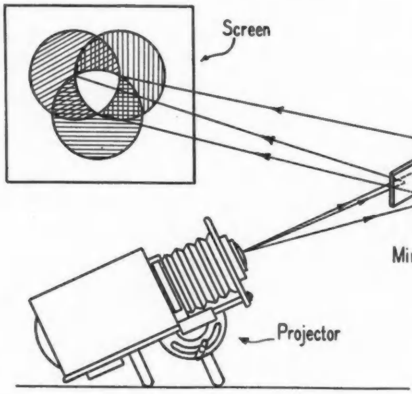

FIG. 2. Arrangement of apparatus.

An effective demonstration of the transmission characteristics of the separate filters may be made with the slide shown in Fig. 3. A slit is cut in a card, and across the slit are laid strips of the gelatin filters; the card is then bound between cover glasses. A portion of the slit is left uncovered to provide a comparison spectrum. If a prism is placed immediately in front of the lens of the projector containing the slide, four spectra will appear on the screen; the three that correspond to the filters and a complete spectrum. It may then be pointed out to the student that a complete spectrum would result from superimposing the spectra of the filters, and that this is precisely what is done when the three colored spots are made to overlap in the preceding experiment.

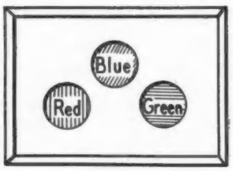

FIG. 1. Slide for color mixer.

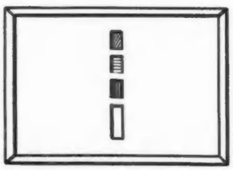
FIG. 3. Slide for comparing absorption spectra.

A Source for the Balmer Series of Hydrogen and Deuterium

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Several interesting experiments can be performed by students if a good source of the Balmer series of hydrogen and deuterium is available. The standard discharge tubes for this purpose are generally inconveniently large and involve the difficult technique of manufacture and outgassing of electrodes; furthermore, they seem to have a very limited life in their optimum condition. A much more satisfactory source is a small electrodeless discharge in water vapor or in a mixture of water vapor and hydrogen. When properly prepared it emits a minimum of the confusing molecular spectrum and is capable of many hours of operation without an appreciable change in the form of discharge. The preparation of the discharge tube is simple and as heavy water is readily available the source may be filled with this vapor and the separation of the lines due to the isotopic shift observed.

The source may be operated from a low power tesla coil or, more efficiently and conveniently, from a small high frequency oscillator. Since an oscillator suitable for this purpose as well as general laboratory work is inexpensive to construct, the one which has been in use will be described briefly. A large power output is not necessary; in fact the few failures in the tubes which we have prepared have been due mainly to an endeavor to make them absorb more than 20–30 watts. Hence a suitable oscillator may be constructed with a type 10 or a type 59, the triode connection being employed for the latter. Either a Hartley or a Colpitts circuit may be used, depending on the type of condenser available. The Colpitts circuit is shown in Fig. 1.

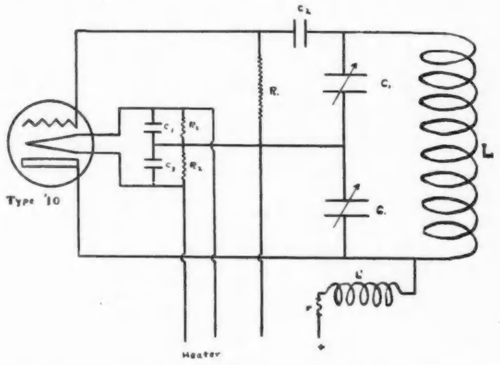

Fig. 1. Circuit of an oscillator for energizing the discharge tube.

With the constants which will be given, the wave-length range is about 20–50 m. The coil L consists of 10 turns of $\frac{3}{16}$-in. copper tubing; the turns are 2.5 in. in diameter and the over-all length is 4 in. The two ends are mounted rigidly on insulators (Fig. 2) and are soldered to copper ribbons running to the stator plates of the ganged condensers C_1. These have a capacity of $120\mu\mu$f per section and with the inductance form a tank circuit with a suitable period. Lighter wire may be used for the rest of the connections. C_2 is a 1000-volt mica grid condenser with a capacity of 0.00025 μf and the grid leak R_1 is a 10,000-ohm wire-wound enameled resistor. The mesh composed of the resistances R_2 of about 50 ohms and the condensers C_3 of 0.01μf, is for dividing the high frequency current between the filament leads. L' is a choke coil to prevent loss of high frequency current from the circuit; it consists of 200 turns of No. 26 wire wound on a cardboard cylinder about 2 in. in diameter. A $\frac{1}{4}$-amp. fuse F protects the tube. The filament may be heated by a small transformer and the plate voltage of 350–450 volts may be obtained from a power pack preferably, or simply from the secondary of a small step-up transformer without rectification.

The best method of applying the output of this oscillator to the discharge tube is to employ a tuned secondary which may be inserted in the copper coils of L. This may be wound on a piece of glass tubing with the ends taped in place (Fig. 2). Two lengths of smaller glass tubing lying in the copper coils insulate it from the primary. The natural period of the coil may be calculated approximately from the inductance formula for a single layer solenoid and the distributed capacity in micromicrofarads, which is given roughly by the radius of the coil in centimeters. A closely wound solenoid of double cotton covered No. 32 wire on a tube 1 in. in diameter and 10 in. long has a natural half-wave-length of about 30 m. With the added inductance and capacity of short leads running from the coil terminals to the ends of the discharge tube such a coil tunes nicely in the range of the oscillator. High frequency sparks $\frac{1}{4}$-in. long may be drawn from the ends of this coil to a wooden-handled screw driver when the primary circuit is tuned to resonance.

The discharge tube (Fig. 2) is merely a straight Pyrex tube $\frac{1}{2}$ in. in diameter and 10 in. long. One end is rounded smoothly and the other is attached through a slight constriction to a bulb of about 250 ml capacity. Observations are made through the rounded end and the constriction tends to confine the discharge to the tube itself.

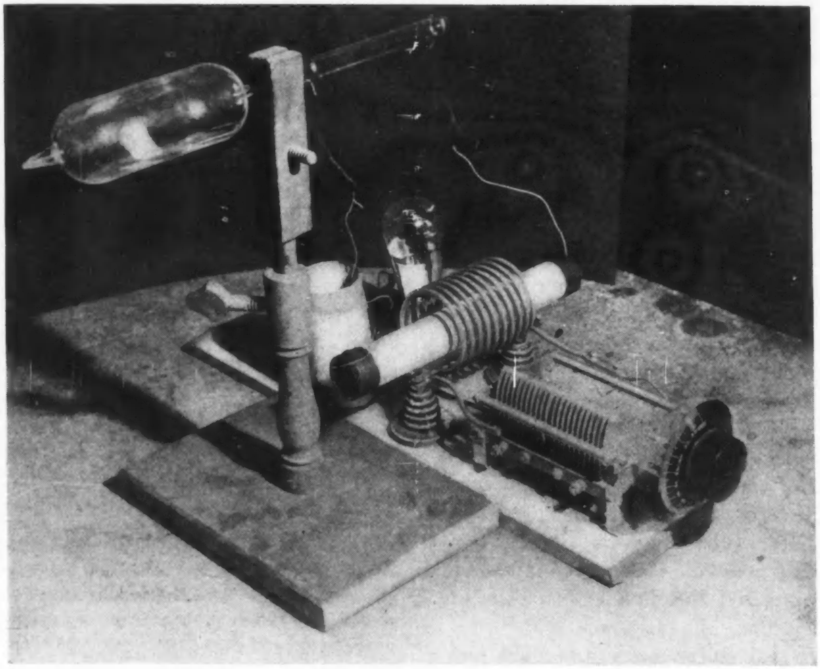

FIG. 2. Photograph of oscillator and discharge tube.

One wire is wrapped around the tube near the rounded end and the other near the constriction. The bulb is included merely to increase the volume so that sorption of gas by the walls during operation has a smaller effect upon the pressure in the tube. A tubulation and constriction from the bulb permit sealing onto an evacuating system. The water supply is placed in a small bulb fitted with a stopcock and sealed to the system. A second stopcock is included between the discharge tube and water and the pump to facilitate the adjustment of the pressure in the tube. A freezing mixture, preferably solid carbon dioxide in equal weights of chloroform and carbon tetrachloride,[1] is placed around the bulb containing the water and the system is well evacuated. The discharge tube should be torched for several minutes, particularly in the region of the sealing-off constriction. The stopcock between the water and tube is then closed and the freezing mixture removed. The terminals of the oscillator secondary are wrapped around the discharge tube and the oscillator tuned. A slight glow may be observed even at the lowest pressures obtainable. The stopcock to the pumps is then turned off and the one leading to the water opened very slightly. The discharge will be observed to pass through a brilliant red condition and then become bluish. The red condition is the one desired for the production of the atomic hydrogen spectrum. If the blue condition is reached before the stopcock can be shut off the excess vapor may be pumped out by opening the stopcock to the pumps and shutting it when the tube is at its brightest red. It is well to run the discharge for several hours on the pump, flushing the tube with water vapor from time to time. After the tube has run steadily in the optimum condition for about an hour, it may be sealed off and used for experimental purposes. It has been found that these tubes which contain only water vapor emit a larger fraction of their radiation in the lower members of the Balmer series than do tubes which have been filled with a mixture of hydrogen and water vapor. However,

[1] D. H. Cook, Am. Phys. Teacher **1**, 90A (1933). With this mixture all fire hazard is avoided and the carbon dioxide floats on the surface of the liquid.

the effect is not very pronounced and unless one wishes to obtain more than 8 or 10 members of the series the foregoing technique is satisfactory and is simpler than filling with hydrogen or deuterium in addition to the water vapor.

After the tube has been prepared it may be used with any ordinary low-dispersion instrument to obtain the Balmer series. It is difficult to obtain good photographs of more than 4 or 5 members with a glass prism instrument as the higher series members are strongly absorbed. The absorption in the glass wall of the tube or in a single glass lens is not troublesome and 10 or 12 members of the series can be photographed with a small quartz instrument. Fig. 3(a) is such a photograph obtained with a 1-min. exposure using a Hilger E-31 spectrograph. Ten members are visible on the original negative. If a comparison spectrum is photographed on the same plate the wave-lengths can be measured and compared with the Balmer formula. Alternatively, a replica grating spectroscope may be used and the wave-lengths of the first four members obtained from the angular settings. The Rydberg constant may be determined to within about 0.1 percent by the latter method.

If a higher dispersion instrument is available the wave-length difference between the hydrogen and deuterium lines may be measured. Fig. 3(b) is a photograph of the H_β lines obtained with a 21-ft. grating. It can be seen that the lines are very narrow and well adapted for use with a high dispersion instrument. A small replica grating has an adequate resolving power; in fact, a 15,000-line grating in the second order has 10 times the necessary resolution. Since the angular separation of the H and D lines is of the order of 1′, a good circle is needed to measure the wave-length difference to better than 10 percent.

An alternative method of measuring this separation is to use a Michelson or Fabry-Perot interferometer. This makes a pretty experiment and the separation of the lines can be obtained very accurately. The source is set up before the interferometer and either a red or blue filter placed between them depending on whether H_α or H_β is to be observed. Starting with equal light paths in the Michelson instrument, at which position the fringes are most distinct, one of the

FIG. 3. (a) Spectrum obtained from a 1-min. exposure with a small quartz instrument. (b) $H_\beta - D_\beta$ doublet obtained with a concave grating.

mirrors is moved gradually away from this position and the fringes are observed to disappear and reappear at regular intervals. The fringes are most distinct when the difference between the number of wave-lengths of the two components in the optical path is an integer. Thus if at one position of greatest distinctness there are n_1 wave-lengths of λ_H and n_2 of λ_D in the path, then $n_1\lambda_H = 2d$ and $n_2\lambda_D = 2d$, where d is half the path length. At the next position of maximum distinctness, $(n_1+n')\lambda_H = 2(d+d')$ and $(n_2+n'+1)\lambda_D = 2(d+d')$ where d is increased by an amount d' which is of course given by $d' = n'\lambda_H/2$. By subtracting these two expressions and inserting the value of n' in terms of d', we obtain

$$\lambda_H - \lambda_D = \lambda_D\lambda_H/2d';$$

or, since λ_D and λ_H are so nearly the same, we may write $\Delta\lambda = \lambda^2/2d'$. Thus $\Delta\lambda$ may be determined from a knowledge of λ and the motion of one of the mirrors. A more accurate value of $\Delta\lambda$ is obtained if the motion of the mirror between, say, ten positions of maximum distinctness is measured. This only amounts to a little over a centimeter for the α lines. The knowledge of this distance d' leads very directly to the difference in the Rydberg constants of H and D. For the α lines,

$$\Delta\nu = \Delta R \cdot 5/36 = -\Delta\lambda/\lambda^2,$$

and hence $\Delta R = 36/10d'$ without regard to sign. For the β lines, $\Delta R = 16/6d''$, where d'' is the mirror motion between positions of maximum distinctness when a blue filter is used. From this value of ΔR and the value of R obtained from the series measurement, the approximate ratio of the masses of D and H may be obtained if the Faraday and the specific charge e/m of

an electron are assumed to be known. Since $R_H = R_\infty/(1+m/M_H)$ and a similar expression exists for R_D, we may eliminate R_∞ and, taking the difference between R_D and R_H small, write

$$\Delta R/R = (m/M_H)(1-M_H/M_D).$$

Since m/M_H is the Faraday divided by e/m, we may solve for M_H/M_D.

Charge-Discharge Key and Timer

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When measuring high resistance by the method of rate of leakage from a condenser the usual form of charge-discharge key with a stop to hold it in the open position is unsatisfactory; in timing the leakage, the key must be operated with one hand and a stopwatch with the other, with consequent error in timing. To overcome this objection the key shown in Fig. 1 was built and has been used with satisfactory results. The important feature is the simultaneous operation of the key and stopwatch.

The base, terminal posts and key lever are of Bakelite. At the left end of the key lever is a narrow strip of metal connected to terminal A by a flexible lead. This strip makes contact with a spring on the upper terminal B when the condenser is being charged, and drops into a small knife-switch type contact on the lower terminal C for discharge, the lever being pulled down by a spring, visible at the left of the metal supporting column.

Two catches, E and F, pivoted at D (Fig. 2) and with arms extending horizontally to the right, hold the key lever either in the charge or in the off position (the latter position is shown in Fig. 1). After the key is set for charging the condenser by pressing on K, pressure on G releases the catch E which is holding it, and catch F stops it in the off, or insulated, position. Simultaneously the lever from G to the catch E presses on the crown of the stopwatch, thus starting the watch at the same time that leakage begins through the high resistance being measured. After the desired time of leak, H is pressed, thus discharging the condenser and at the same time stopping the watch. The time of leak can then be read from the watch. When ready to take another reading pressure on K will bring the key again to the charge position and at the same time reset the stopwatch at zero.

The watch is held in a ring support at a distance from the axis D that depends on the length of the stroke required to operate the watch. By using buttons K and H only, this key may be used as an ordinary charge-discharge key, with or without the watch being in place.

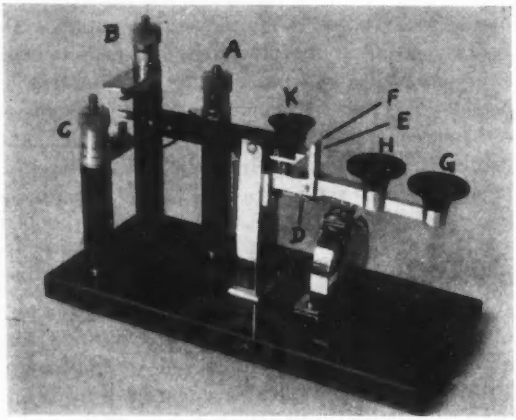

Fig. 1. Photograph of key and timer.

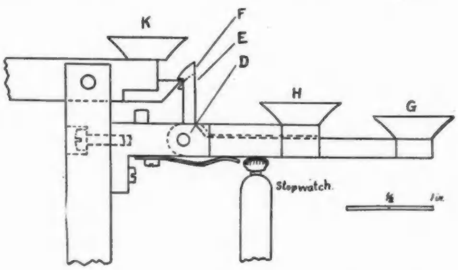

Fig. 2. Diagram of operating mechanism.

A Demonstration Apparatus for Illustrating the Flow of Electricity in Circuits

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ALTHOUGH it is impossible to illustrate all that takes place in an electric circuit by means of the well-known water analogy, it nevertheless aids in explaining most of the difficult points that the beginner will encounter. The student cannot see electricity move through wires but he can see the colored water in an apparatus like the one described in this paper.

The apparatus consists of two tanks, *G* and *T*, Fig. 1; a centrifugal pump, *P*, which is connected to a small motor by a belt *B*; and three brass pipes which connect the two tanks. One of these pipes conducts colored water from the lower tank, *G*, to the pump, and then from the pump to the upper tank, *T*. The second pipe serves as an overflow, when tank *T* is nearly full; the overflow water returns to tank *G*. The third pipe also transmits water from the upper tank to the lower, but differs from the overflow pipe by having a solid rod inside of the horizontal part of the pipe; the rod nearly fills the pipe, so there is considerable resistance to the flow. Six vertical glass tubes are connected to this horizontal pipe; the heights of the water in them indicate the pressures at various points along the pipe. The outlet end of this third pipe has a stopcock. The tank *T* is equipped with a glass water gauge.

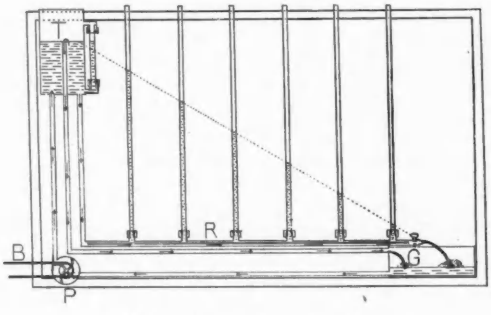

FIG. 1. Diagram of apparatus.

The dimensions of the apparatus are: height, 60 cm; length, 1 m; inner diameter of pipes, 1 cm; inner diameter of glass tubes, 8 mm; capacity of each tank, 1.2 l. The pump has an inner diameter of 4.1 cm, with each of the four impeller blades 2 cm long, 1.5 cm wide and 2 mm thick; its capacity is 3 l/min. at 1700 r.p.m., sufficient to keep the upper tank filled and a small stream passing through the overflow.

If the stopcock is closed all of the glass tubes fill to the level of the water in *T*. By removing the stopcock one can pull the rod part way out of the pipe. When it is halfway out, the three glass tubes at the left will be filled almost to the original level whereas the surfaces of the water in the remaining tubes will lie in a straight line having a much steeper slope.

The writer wishes to acknowledge helpful suggestions from Mr. H. I. Pratt who constructed the apparatus.

Proposed A. A. P. T. Awards for Distinguished Teaching and Contributions to Teaching

AT the last annual meeting an anonymous donor offered to finance for a period of three years an annual award for distinguished teaching and contributions to teaching, the award to consist of a medal, accompanied by a certificate from the American Association of Physics Teachers. The committee consisting of Professors Cope, Dodge and Cornelius appointed to consider the problem will present recommendations at the annual meeting at St. Louis for the method to be employed in making the award.

DISCUSSION AND CORRESPONDENCE

Is There a Centrifugal Force?

ONE wonders whether a student seeking information on the topic of centrifugal force would be greatly enlightened by consulting the various treatments found in the elementary textbooks. The writer's criticisms of these treatments fall under three heads: (1) The definitions of centrifugal force found in about a dozen texts examined were either incorrect, misleading or unnecessarily vague. (2) The idea of inertial force commonly is introduced for the first time at this stage, rather than in connection with the simpler case of rectilinear motion. (3) It is probably better to refrain from the use of the idea of inertial force altogether in elementary treatments.

(1) One author asks if a centrifugal force exists. Another states that it is not a *real* force. Some label it "so-called," or say that it merely *seems* to pull from the center of rotation. One book states that the term is misleading because it "implied the existence of an outward acting force." What aspect of the (always dual) force is meant here? Centrifugal force *is* an outward acting force, but it acts on the center of rotation; for example, on the hand that is whirling a stone at the end of a piece of string. Perhaps one reason for this confusion is that here for the first time a reaction has been given a special name, rather than being labeled merely as a *reaction*.

In two of the books examined a definition of centrifugal force is not given. One of these books contains the statement that "the balls [of a governor] move outward because of the centrifugal force which acts upon them." (Note that here the centrifugal force is said to act *on* the rotating body.) In the other book the term "centripetal" is not used; the centrifugal drier is mentioned as "utilizing the principle of centrifugal force." One other text speaks of the centripetal force being "resisted" by an equal and opposite force, thus bringing in the idea of an inertial force.

(2) Why is it that the concept of *inertial force* is so often first mentioned in connection with motion in a circle when as a matter of fact it is no different from the same concept in rectilinear motion? The student is likely to form the idea that the concept is peculiarly essential, or even unique, to this particular problem. Some authors identify the centrifugal force with inertial force, and warn the reader that there is no external force acting outward on the rotating body. Such a warning may be necessary, but should the centrifugal force be identified with the inertial force? Certainly it is equal to it. But the inertial force "acts" *on* the rotating body, whereas the centrifugal force, if we abide by the usual definition, acts on the center of rotation.[1] The argument can best be made clear by the consideration of two simple examples.

(i) Two particles, A and B, are moving along the line that joins them. B acts on A with an unbalanced force F, thus giving the latter an acceleration F/m. The reaction on B is equal in magnitude and opposite to F. If we wish to make an equilibrium problem out of this kinetic problem, the inertial force, equal in magnitude to F and oppositely directed, is introduced; then $F-ma=0$. This is one aspect of d'Alembert's principle. Note that although the reaction is due to the inertia of A, *it acts on B, whereas the inertial force by definition acts on A.*

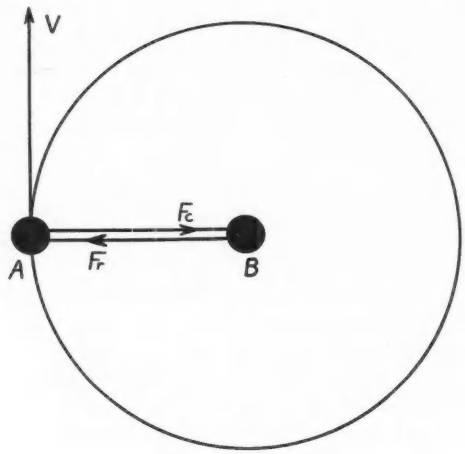

FIG. 1

(ii) Particle A in Fig. 1 is revolving about B with constant speed. The centrifugal force F_r is simply the reaction of the centripetal force F_c. The centrifugal force is exerted *by A* and acts *on B*; for example, on the hand holding the string tied to a whirling stone. Is it true then that one cannot find a body which exerts this centrifugal force? This case differs from the preceding one only in that the acceleration involves a change of direction alone, rather than change of speed alone.

(3) Inertial force is not an indispensable concept and, in the writer's opinion, had better not be introduced in a first course. If it is to be employed at all it should be introduced earlier, in the simpler case of rectilinear motion, and it should be recognized that its function is simply to reduce a system of unbalanced forces to a system in equilibrium. The use of the concept also involves the danger of confusing a student in regard to Newton's third law. Without adding to their difficulties many students already have trouble enough in grasping the idea that the action and reaction do not act on the same body and are not equilibrating forces.

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[1] In his *Introduction to Theoretical Physics*, L. Page states that the kinetic reaction "is often referred to as the centrifugal force."

What Educational Needs Have Favored the Development of Survey Courses in the Natural Sciences?

IN the September issue (p. 97) Dr. Robert J. Havighurst has presented data on survey courses in physical and biological science and he has suggested some of the advantages and disadvantages attributed to them. With this article in hand, it appears that there may be some interest in further discussion of the conditions out of which these courses have developed and possibly some further comments on the functions which such courses may serve.

An examination of catalogs shows that most of the programs for instruction in the sciences are organized on the plan of separate departments for each of the divisions of science. Differentiation has gone on until it is now not unusual to find in colleges and universities as many as 8 to 10 distinct science departments. The circumstances favoring this differentiation are well supported by college and university traditions. Generally new departments are admitted in response to a recognized opportunity for expansion within a new area of knowledge. The strength of a department is rated in terms of its contributions to knowledge. This has served as a powerful stimulus to scholars, and colleges and universities have tended to become merely contributors to knowledge.

It seems fair to say that in the traditional college but little provision has been made for consideration of the relations of knowledge to human welfare. Knowledge has been stored in the archives to be used by students in the further extension of knowledge. In the undergraduate divisions, students have been prepared for a scholarly career in a field of research or for work in one of the learned professions. Early in their careers as college students, young men and women become absorbed in the work of a special department. Not many years ago the faculty in physics of one of the foremost American universities recommended that majors in this department be required to offer for graduation 55 semester hours of work in physics. The traditions molding the character of the liberal arts college have favored an institution suitable for giving specialized education to an intellectual élite.

It is interesting to note that the factors that have influenced the character of the colleges have, at the same time, had a powerful influence on the work of the secondary school. The traditional scientific subjects of grades eleven and twelve are courses in physics and chemistry and these have been essentially abbreviated college courses in these subjects.

Along with the evolution of society there has arisen a demand for a program of education that is directed toward the attainment of broader aims and there is abundant evidence that colleges are responding to this demand. A review of aims and objectives of college education shows increasing emphasis on general education. The term "general" is used to contrast with the terms "special" and "vocational." In support of this emphasis there are frequent references in college catalogs to the influence that scholarly works, particularly scientific developments, are having on individual and community life of today.

It seems fair to say, by way of contrasting the two functions of college education, that specialization has tended to favor the expansion of knowledge without regard to its use in human relations. Specialization has tended to favor knowledge for knowledge's sake. General education centers more on human interest and human welfare; it seeks to use knowledge in human activities. It is not assumed that there is a sharp line of demarcation between specialization and generalization, but the terms are useful for indicating difference in emphasis. The change in emphasis revealed in the statements of aims and purposes of college education undoubtedly has favored the development of "survey-type" courses, not only in science but in the other broad academic fields.

With recognition of the aims and purposes of general education the appropriateness of the special sciences for their attainment is immediately brought into question. Obviously, important contributions to human interest and human welfare have come from all fields of science and hence a program in which the student has opportunity to work in but one or two of the specialized fields has seemed inadequate. Furthermore, the content of special courses, selected for purposes of specialization, seems ill-adapted and in some measure unacceptable to students seeking general education. These and other considerations have caused college administrators and teachers of science to include in the college offering, courses which give to students broader experiences within the science fields. Survey courses have been designed to give this broader experience.

In response to the demand for survey courses, two types have evolved. In describing these courses Havighurst has appropriately used the terms *comprehensive* and *selective*. In order of emergence the comprehensive courses come first. Subject matter of the comprehensive courses is chosen from the major divisions of science and arranged so that the student may "survey" these divisions. A typical survey of physical sciences "is designed to orient freshmen in the fields of astronomy, chemistry, geology, and physics. Through introduction to these sciences it aims to give a concrete conception of the physical world, some knowledge of scientific method and the part it has had in the intellectual life of the race, and the contributions of the physical sciences to the solution of contemporary problems." Another, broader in its scope, is "A course to teach the fundamental laws of physics, chemistry, and biology; to present, by practical demonstrations, laboratory techniques; and to lead students into the field of scientific thought through library research."

Usually these comprehensive courses are designed by the science faculties, working collectively, and each division represented in the college is "surveyed." The guidance objective undoubtedly has had some influence in favoring this type of course. It has been stated that the survey of the special sciences will be useful as a guide to the student in selecting his field for vocational or specialized study. A characteristic feature of these first courses is that they survey the sciences.

Increasing emphasis on human activities and human relations has favored the development of the second type of course. In these *selective* courses, areas of human interest and activity are used as criteria in the selection of content

for instruction. These areas may include: (1) Human growth and development; (2) maintaining personal and public health; (3) recreational activities; (4) economic-industrial life, including (*a*) production, control, and consumption of energy, (*b*) production and consumption of food, (*c*) production and consumption of materials (metals, alloys, ceramics, etc.); and (5) thinking about life and the universe, including (*a*) aspects of man's scientific world-model, structure and evolution of the physical universe, evolution of life, factors that relate to and condition human thinking and action, etc., and (*b*) relations of science to other fields of knowledge. This newer type of course surveys these areas of human interest.

Selective courses may be less comprehensive. Some are limited to a particular theme from pure science, such as evolution or energy, following it through the various areas of science in which it appears; in such courses the theme is chosen because of its interest and importance in human affairs. These selective courses may be contrasted with the comprehensive type for in them no effort is made to give a "comprehensive" survey of science fields. Content is *selected* for particular purposes and criteria such as are suggested by the foregoing definition of areas are used for guidance in making selections. The 31st Yearbook of the National Society for the Study of Education[1] entitled *A Program for Teaching Science* seems to have been an effective stimulus to the development of this type of course.

The terms *analytical* and *descriptive*, also used by Havighurst, are useful in describing both types of survey courses. In my opinion (which seems to be in agreement with Havighurst's), the terms *analytical* and *descriptive* are subheadings under comprehensive and selective. Thus, courses may be described as comprehensive and analytical, comprehensive and descriptive, selective and analytical, or selective and descriptive.

It is, of course, difficult to predict what the future holds in store for survey courses. There seems to be good reason to believe that the purposes that have brought them into being will receive increasingly large recognition in the planning of both secondary schools and colleges. The present efforts to develop courses should be looked upon as experimental. As experience accumulates from efforts to attain the aims of general education, we may expect clearer understanding of the means to use. Experimentation with survey-type courses is also in progress in secondary schools. It seems certain that some and probably a good deal of what is now being done in colleges will rightfully find place ultimately in the secondary school.

The issues raised in these developments will, it seems, tend to bring into question the particular functions of secondary and collegiate education particularly as these functions relate to general education. Experience with survey courses doubtless will contribute clarity to the definitions of these functions.

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[1] Public School Pub. Co., Bloomington, Ill. (1932).

The Exercise of Student Originality in the General Physics Laboratory

Anyone who has had to conduct laboratory work in connection with elementary college physics will agree that it is difficult to prevent the work from becoming just a routine; even the best students are inclined to approach it as a weekly stint, rather than as a chance to experiment. The author has had the opportunity during the past year to try a more flexible plan of laboratory work, with interesting results.

Briefly, the students were told early in the course that during the year they would be required to suggest and perform two independent experiments in place of any two they wished to omit from the usual routine. This was mentioned again at times, and finally the students were requested to bring in their ideas for consultation. By the end of the semester the plan was well under way.

The proposed experiments were sometimes trivial, sometimes over-ambitious; for example, one enthusiastic chap wanted to measure the variation of mass with velocity. In no case, however, was the student embarassed by being discouraged from his plan. He was told to design an apparatus, calculate its possibilities, and report. Usually, a little time with pencil and paper scaled down his ideas to proper size.

Eventually some interesting experiments were in progress. The construction of the apparatus frequently involved lathe work, glass blowing, soldering, etc., all of which was done by the students. Several students built a very satisfactory apparatus for measuring the acceleration due to gravity, and the Foucault effect. Others measured the viscosity of lubricating oils as a function of temperature. Two students built an improved Kundt's tube apparatus. One musically minded boy built some chimes. Altogether about eighteen projects were carried out, scattered well over the field of physics.

The most significant result of the plan was its effect on the laboratory work in general. Few of the students availed themselves of the privilege of omitting the regular experiments and the quality of their laboratory work was greatly improved. Furthermore, there seemed to be an absence of the irritating idea which so many students have that laboratory apparatus should be like machines, capable of grinding out results with high speed and efficiency. The students had learned to experiment. There was no noticeable effect on class work, however, a fact which may be a bit surprising in view of the enhanced interest displayed.

Such a plan of instruction takes much time and effort, and may on that account be impracticable unless plenty of assistance is available; but in the opinion of the author it is well worth while where it can be put into effect.

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University of Pittsburgh.

Why Not the Poundal?

IN a recent letter[1] Professor Owen argues for the exclusive use of the pound as an English unit of force, and for the suppression of the poundal. He would have no absolute units of force and work in the English system. I much prefer to use the poundal and the foot-poundal. I believe that elementary physics is easier for students if these units are employed and that the conversion to pounds and foot-pounds is so simple that the necessity of changing constitutes no disadvantage.

It is true that the foot-pound is so common a unit that it cannot, and should not, be displaced. It is true that we usually remember the horsepower in terms of foot-pounds and seconds, and the British thermal unit in terms of foot-pounds. The advantage of the poundal is essentially this, that by using it one has the English units which correspond perfectly to the dyne and the erg. I remember asking, when I was taking college physics, what one would get if he worked out $mv^2/2$ with m in pounds and v in feet per second. We could not tell, because we had not been taught, but the lack of a unit corresponding to the erg seemed to us a defect. If centrifugal force is given by mv^2/r, the substitution of English units gives poundals. One thus secures a symmetry in the two systems which, to me at any rate, is intellectually satisfying. If the pound is a unit of mass then there must exist, whether it is used or not, that absolute unit of force in the English system which might be called anything, but is properly called the poundal, and the corresponding unit of work. They are there, so to speak, and the student with a feeling for system enjoys them. Why should they be suppressed? It is easier to remember two things, related and supplementary, than to remember one.

This is not the only advantage. The exclusion of the poundal entails the introduction of a new unit of mass, the so-called *slug*, to be used in the formulas $mv^2/2$ and mv^2/r to give foot-pounds and pounds, respectively, for energy and force. But if one has already worked out the formulas in the c.g.s. system, which certainly cannot be omitted, the introduction of the slug is something of a subterfuge and an evasion. Gravitation does not affect the mass of a body. There is accordingly no need for a gravitational unit of mass, which is artificial, and logically unnecessary. Gravitation does give us forces, and there is an obvious gravitational unit of force. Is it not awkward to have the acceleration due to gravity apparently entering the expression $(F/m)^{\frac{1}{2}}$ for the speed of a transverse wave in a rope? Or to have moment of inertia expressed in *slug feet squared?* "Slug feet" suggests the gastropod locomotion of the snail. Using a gravitational unit for mass obscures the fact that the pound is a gravitational and variable unit of force. In the justly esteemed textbook, *A Survey of Physics*, Professor Saunders says: "The Slug is known as a 'British Engineering Unit' of mass. So far as we know, British engineers avoid it, and, as we do not need it, we shall follow their example."

I hope that no educational dictator puts the poundal on his prohibited list. There is a beauty of symmetry and completeness about our system of grams, dynes and ergs, with pounds, poundals and foot-poundals, that makes the system adequate and attractive and therefore easy to learn.

W. W. SLEATOR

Department of Physics,
University of Michigan.

[1] G. E. Owen, Am. Phys. Teacher **3**, 39 (1935).

A Projection Electroscope

CONVENIENT arrangements for projecting an electroscope image have been recently described.[1,2] A projection device which the writer has used with success is shown in Fig. 1. It can be set up quickly and is so arranged that the student may readily see how the electroscope is constructed, watch the screen upon which the image is projected and observe the manipulation of the electroscope by the demonstrator without a shift of vision. The device consists simply of a box A about 22 cm high, with glass sides and a 22×15-cm hard rubber top. A brass rod with a knob of 1 in. diameter passes through the top. Gold leaves are attached to the other end of the rod as usual. A box B houses the 75-watt lamp used for illumination. The distance of the lamp may be varied with respect to a condenser lens of 10 cm focal length until the beam of light is approximately parallel. A clear image of the leaves is formed on a 50×60-cm aluminum-painted screen by means of an adjustable lens of 5 cm focal length. The screen is mounted on a pedestaled frame on the lecture table near the end and while in use is turned about 45 degrees with respect to the beam of light; this gives the class an unobstructed view of the shadow of the leaves.

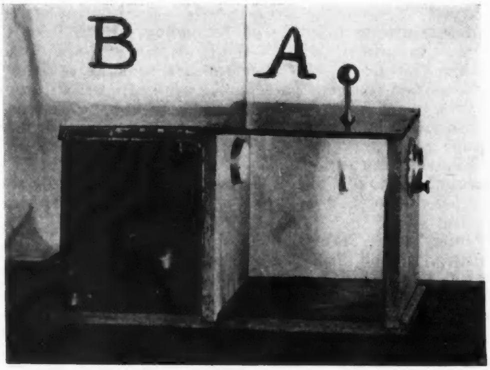

FIG. 1. Photograph of projection electroscope.

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Department of Physics,
N. J. C., Rutgers University.

[1] J. J. Heilemann, Am. Phys. Teacher **2**, 28 (1934).
[2] H. E. Hammond, Am. Phys. Teacher **3**, 39 (1935).

Available Graduate Appointments and Facilities for Advanced Study in Various Universities and Colleges—1936–1937

The present survey for the academic year 1936–1937 continues the annual compilation of opportunities for graduate study in physics, the first of which was published in the February, 1935 issue, p. 42. The information given of course must be regarded as estimates rather than exact designations of the conditions that will prevail at these institutions next year. The Editor wishes to express his appreciation of the cooperation of the staff members of the departments listed, without which this information could not be assembled.

Few appointments are available compared with the probable number of candidates and the mere publication of the list obviously does not affect this situation. The purpose of the information is to enable the student to choose intelligently the institutions in which he desires and can afford to study and hence to render it unnecessary for him to send out applications promiscuously or to depend entirely on information obtained casually or through connections of a personal nature. If the list is used judiciously by students and their advisers, its publication will tend to prevent rather than encourage an unnecessarily large number of applications.

The student, with the help of his adviser, should select a small number of institutions in which he feels best qualified by his interests and abilities to study, and in any one of which he would be willing to accept an appointment as soon as it is offered. When he accepts an appointment, other pending applications should be withdrawn immediately.

Unless otherwise specified, the application must be filed with the person designated *before March 1;* if no person is designated, address the head of the department of physics. "M only" means that the master's degree is the highest degree granted. "No form" means that a special application form is neither furnished nor required. The numerals preceding the parentheses indicate the probable number of vacancies for next year; those in parentheses indicate the total number of appointments existing in the department; e.g., 2(3) *fellows* means that three fellowships exist, two of which probably will be vacant and open to competition next year. Except where otherwise indicated, appointees do not have to pay tuition (t.) or fees (f.). Under *R* are listed fields of research that are stressed in the department and under *U* unusual facilities for research and study.

A. and M. College of Texas, Dean T. D. Brooks, College Station, Tex. June 1; M only. 1(1) *graduate assistant,* lab. teach., **$405** less **$25** f. A nonresident must pay the nonresident t. of his state univ. *R:* spectroscopy; x-ray diffraction; polarimetry.

Boston College, Chestnut Hill, Mass. June 1; M only; no form. 3(3) *graduate assistants,* 8 hrs./wk., general lab., **$600** less **$20** f. Appointees must have had 3 yrs. physics, advanced calculus and differential equations. *R:* electronics. *U:* electric oscillations and electromagnetic waves.

Brown University, Graduate Registrar, Providence, R. I. 2(4–6) *graduate assistants,* 18–20 hr./wk. lab. or research asst., **$500**; 1(1) *fellow,* **$500** less **$60** t./course (t. may be remitted in return for some service); 2(3) *minor assistants,* 6 hr./wk. asst., t. and f. remitted; 1(1) *scholar,* t. and f. remitted. *R:* properties of single metal crystals (e.g., electron diffraction, photoelectric effect, contact potentials, conductivity, magnetic susceptibility); theoretical and experimental acoustics; atomic theory calculations (e.g., atomic wave functions); foundations of physics. *U:* single metal crystal technique; electro-acoustics; good library.

Bryn Mawr College, Graduate Dean, Bryn Mawr, Pa. 1(3) *half-time demonstrators,* lab. asst., **$750**; 0(1) *resident fellow,* 3 hr./wk. library, etc., 1 yr. graduate work prerequisite, **$860**; 0(1) *resident scholar,* **$400**. Fellows and scholars pay **$320** t. and **$500** board and room.

California Institute of Technology, Graduate Dean, Pasadena, Calif. 8(20) *graduate assistants,* 15 hr./wk. maximum, room, board, t. and f. *U:* nuclear physics; spectroscopy; x-rays; physics of solids; low temperatures; geophysics; etc.

Colorado College, Prof. P. E. Boucher, Colorado Springs, Colo. M only. 1(1) *graduate teaching fellow,* 6–10 hr./wk. lab. asst., remission of **$225** t. *R:* x-rays; high-frequency measurements; optics; photography.

Duke University, Dean W. H. Glasson, Durham, N. C., Mar. 15. 2 *graduate assistants,* **$600–700**; 1 *fellow,* **$600**; 8 *scholars,* **$400**. All appointees pay **$280** t. and f. *R, U:* spectroscopy, magnetism; atomic and nuclear physics.

Emory University, Emory Univ., Ga. M only. 2(2); *graduate assistants,* general asst., **$400–225** less **$225** t.; several *scholars* t. and f. of **$225** remitted. For assistantships, apply by letter before May 1 to Prof. W. S. Nelms; for scholarships, apply on special form before Mar. 1 to Dean G. C. White.

Harvard University, Cambridge, Mass. 4 (many); *half-time instructors,* teach., $900–1000 less $200 t.; 2(4) *half-time assistants,* teach., $900 less $200 t.; 5(7) *fellows* and *scholars,* $500–900 less $400 t. For fellowships and scholarships apply on form before Mar. 1 to Dean of Graduate School of Arts and Sciences; for other appointments immediately by letter to department chairman. *U:* high pressures; electric oscillations; spectroscopy; cosmic rays; mass spectrography; ionosphere studies; acoustics.

Iowa State College, Dean R. E. Buchanan, Ames, Ia. 3(7) *teaching fellows,* lab. asst., **$450**; 1(1) *research fellow,* research, **$450**; 3(3) *research scholars,* research, **$225**. All appointees pay **$36** t. and f. *R:* applied physics. *U:* electronics; physics of crystals; cathode rays; biophysics; soil physics; photography; illumination.

Louisiana State University, Prof. D. V. Guthrie, Baton Rouge, La. M only. 5(8) *graduate fellows,* lab. teach., grading, **$360** less **$60**. *R:* x-rays; electronics; photoelectricity.

Massachusetts Institute of Technology, Prof. John C. Slater, Cambridge, Mass. 4–5(18) *teaching fellows,* **$600–800** less **$250** t.; 18 *half-tuition scholars,* remits t. of fellows and awarded to them on separate application; 10 *tuition scholars,* remission of **$500** t. required of full-time students. *U:* spectroscopy; electronics; x-ray crystal structure; high voltage and nuclear structure; applied optics; classical and modern theoretical physics.

Mount Holyoke College, South Hadley, Mass. M only. 1(1) *fellow,* **$600**; 0–1(1) *graduate assistant,* library and lab. asst., **$575**.

Pennsylvania State College, Prof. W. R. Ham, State College, Pa. Feb. 1. 4(12) *graduate assistants,* 12 hr./wk. service, **$700**; 3(6) *graduate scholars,* 4–5 hr./wk. service, t. and f. remitted. For following appointments in phys. chemistry and chem. physics, apply to Prof. W. P. Davey: 2(6) *graduate assistants,* 12 hr./wk. service, **$700**; 1(2) *graduate scholars,* 4–5 hr./wk. service, t. and f. remitted; 0(1) *research assistant,* 16 hr./wk. research, **$400**. *U:* electronics; diffusion of gases through metals; visible and ultra-

violet spectroscopy; crystal structure; liquid and solid solutions; specific heats at liquid hydrogen temperature.

Polytechnic Institute of Brooklyn, Prof. Erick Hausmann, Brooklyn, N. Y. Apr. 1, M only (Ph.D. in Chem.), no form. 1–2(2) *graduate scholars*, grading, stipend as yet undetermined. *R:* optics; electricity.

Princeton University, Prof. E. P. Adams, Princeton, N. J. 2–3 *fellows*, **$800**; 4–6 *research assistants*, half-time, **$650** less **$100** t.; 1–2 *Proctor fellows*, **$1400** (rarely awarded to a first-year student); 1 *scholar*, **$400**. All appointees pay **$5** f. *R:* line spectra; infrared spectra; fluorescence; dispersion in gases; mass spectrography; nuclear physics; quantum mechanics and its applications to atomic and molecular problems. *U:* spectroscopy; high voltage; mass spectrographs.

Rice Institute, Prof. H. A. Wilson, Houston, Tex. Apr. 1, no form. 1–2(3+) *fellows*, 6 hr./wk. lab. asst., **$500** less **$34** t. and f.; 10 *student assistants*, grading, apparatus, etc., 50 cts./hr. *R:* fields not limited, but nuclear physics predominates.

Rutgers University, New Brunswick, N. J. No form. 2(4) *graduate assistants*, lab. asst., **$450** and room; 2 (varies) *graduate scholars*, t. and f. remitted.

Syracuse University, Prof. R. A. Porter, Syracuse, N. Y. M only; no form. 5(5) *graduate assistants*, 12 hr./wk. lab. teach., **$500–600** less **$5** f. *R:* thermal conduction and expansion; magnetism; electrical conduction in gases; spectroscopy.

University of California, Berkeley, Calif. Feb. 20. 5–8(18) *teaching assistants*, lab. asst., grading, etc., **$600** less **$52** f.; (2–3) *graduate fellows*, **$300–1200** less **$52** f.; various *graduate fellows*. Nonresident t. of **$150** usually remitted. Applicants not already in residence should apply for assistantships. *U:* spectroscopy; nuclear physics, mobility of ions; mathematical physics.

University of California at Los Angeles, Prof. Vern O. Knudsen, Los Angeles, Calif. M only; no form. 2(2) *teaching assistants*, lab. asst., **$500**; 5(5) *readers*, grading, **$25–175**; 1(1) *research assistant*, **$300**. All appointees pay **$46** f.; onresidents also pay **$150** t.

University of Chicago, Univ. Committee on Fellowships and Scholarships, Chicago, Ill. 3(6) *scholars*, lab. asst., t. and f. of **$100**/quarter remitted; 2(6) *fellows*, lab. asst., **$500–600** less **$300** t. and f.; 2(5) *assistants*, part-time teach., **$750** less **$33.33** f./course.

University of Colorado, Boulder, Colo, 2 *part-time instructors*, lab. and class asst., **$800** less **$63** t. and f.; 1 *graduate assistant*, lab. asst., **$600** less **$96** t. and f.; 1–3 *university fellows*, **$200**; 1–3 *scholars*, t. and f. for physics remitted. Instructors and assistants apply to Prof. W. B. Pietenpol; others to Graduate Dean.

University of Florida, Prof. R. C. Williamson, Gainesville, Fla. May 1, M only. 2(4) *graduate assistants*, lab. asst., **$360** less **$10**. *R:* spectroscopy; Raman effect; x-rays; dielectrics.

University of Idaho, Moscow, Idaho. Apr. 15; M only; no form. 1(1) *teaching fellow*, lab. teach., **$500**.

University of Illinois, Prof. F. W. Loomis, Urbana, Ill. 6(24) *graduate assistants*, half-time teach., **$700**; 1(2) *fellows*, quarter-time teach., etc., 1 yr. graduate work prerequisite, **$500–600**; 2(3) *scholars*, quarter-time teach., etc., **$300**. *U:* spectroscopy; nuclear physics; acoustics; theoretical physics.

University of Maine, A. L. Fitch, Orono, Me. M only; no form. 1(1) *graduate fellow*, lab. asst., **$750**.

University of Michigan, Ann Arbor, Mich. No form. 6(8–10) *teaching assistants*, class and lab. teach., **$100–500**; 2(1–3) *fellows*, **$500**; 3(1–5) *research assistants*, research asst., **$100–800**; 1(1–2) *teaching fellows*, teach., **$500–1500**. Nonresidents must pay t. *U:* infrared spectroscopy; nuclear physics; electronics; spectroscopy; x-rays; sound; vacuum tubes and radio; theoretical physics.

University of Nebraska, Prof. H. H. Marvin, Lincoln, Neb. M only. 1(3) *graduate assistants*, 6–8 hr./wk., charge of lab. sections, **$480** less **$6**. *R:* spectroscopy; x-rays; conduction of electricity in gases; electrical and magnetic measurements.

University of Oklahoma, Prof. H. L. Dodge, Norman, Okla. Apr. 1. 2(6) *graduate assistants*, 18 hr./wk. lab. asst., **$400**; 0(1) *research fellow*, 12 hr./wk. research, **$400**; 2(3) *university scholars*, t. and f. remitted. *R:* Raman effect and molecular structure; geophysics; photoelectricity; soft x-rays; Brownian motion.

University of Pennsylvania, Dean H. Lamar Crosby, Philadelphia, Pa. 2(2) *Tyndale* and *Frazer fellows*, **$600**. Appointments open to general competition in the graduate school: *Harrison research fellows*, **$1500**; *Harrison fellows*, **$600**; *Harrison* and *University scholars*, **$200** down to t. remitted. All appointees pay minor fees. Usually no service is required. *U:* soft x-rays; radioactivity; luminescence; electron diffraction; optical constants; mathematical physics.

University of Rochester, Prof. L. A. DuBridge, Rochester, N. Y. Mar. 20. 2(4) *graduate assistants*, lab. teach., **$600**; 1(1) *reader*, grading, **$200**; 0(3) *fellows*, research asst., research experience required, **$700**; 1(4) *assistants in Institute of Applied Optics*, teach. and research (apply to Prof. T. R. Wilkins), **$600**. All appointees pay **$5** f. *R:* electron emission; radioactivity; nuclear physics; optics; biophysics. *U:* cyclotron; ultraviolet spectroscopy.

University of South Dakota, Vermillion, S. Dak. May 1; M only, with major in mathematics; no form. 1(1) *graduate assistant*, lab. asst., **$250** less **$70** t. and f.

University of Southern California, Los Angeles, Calif. No form. 3(3) *graduate assistants*, lab. asst., **$180** less **$240** t. and f. *R:* electrical measurements; vacuum tube phenomena.

University of Texas, Prof. S. Leroy Brown, Austin, Tex. June 1; no form. 5(10) *teaching tutors*, charge of lab. sections; **$300–1000** less **$50** t. and f.; 5(10) *graduate assistants*, lab. asst., **$150–300** less **$50** t. and f. *R:* geophysics; thermionics; electric waves; optics; astrophysics.

University of Virginia, University Station, Va. 3(6) *service fellows*, lab. and quiz sections, **$500**; 1(1) *service fellow*, lab. and quiz sections, **$250**. Also the following Philip Francis DuPont fellowships: 1–2(1–2) *junior fellows*, $300–200; 1–2(1–2) *senior fellows*, $500–400; 1(1) *research fellow*, $750–1000. For service fellowships, apply to Prof. L. G. Hoxton; for other appointments apply to Secretary to Graduate Dean.

University of Wisconsin, Madison, Wis. 1–2 (4–5) *research assistants*, 20 hr./wk. service, **$600**; 3–4(12–13) *teaching assistants*, 14 hr./wk. lab. teach., **$650**; 0(1) *fellow*, 4 hr./wk. service, **$600**; 1–2 (varies) *alumni research fellows*, **$400–700**; 1 (varies) *scholar*, **$250**. All appointees pay **$55** f.; fellows and scholars also pay small lab. f. For assistantships apply to Prof. J. R. Roebuck before Mar. 1; for other appointments apply to Dean E. B. Fred before Feb. 15. *U:* nuclear physics; photoelectricity; spectroscopy; thermodynamics.

Virginia Polytechnic Institute, Chairman of Committee on Graduate Studies, Blacksburg, Va. May 1, M only. 2(2) *graduate assistants*, grading, lab. asst., **$300**; 2(2) *fellows*, grading, lab. asst., **$400**.

Washington University, Prof. G. E. M. Jauncey, St. Louis, Mo. Feb. 15. (3) *graduate assistants*, half-time teach., **$700** less **$50** t.; (2) *departmental assistants*, part-time service, **$550** less **$100**; (1) *fellow*, **$500** less **$50** t.; (2) *scholars*, **$200** less **$50** t. Probably no vacancies. *R:* x-rays, electronic and atomic collision phenomena; wave mechanics.

Yale University, Prof. John Zeleny, New Haven, Conn. No form. 4(6) *laboratory assistants*, lab. asst., grading, **$800** less **$315** t. and f. *U:* magnetism, spectroscopy, radioactivity, nuclear physics, x-rays.

[*This list will be continued in the February, 1936 issue.*]

Teaching Aids

Booklets and Pamphlets

A Discussion of Some of the Principles of Acoustical Insulation. V. L. Crisler. 12 p., 5 fig. U. S. Bur. of Standards Cir. 403. *Superintendent of Documents* (Washington), 5 cts. Transmission of sound through partitions, effect of openings, etc.

Introduction to Atomic Physics: Lesson Assignments and Notes. John A. Eldridge, Professor of Physics, University of Iowa. 40 p., 25 fig. *Author*, gratis to teachers. A syllabus of a course in modern physics with references and questions, and with supplementary notes to the author's *Physical Basis of Things* [see Am. Phys. Teacher **3**, 92 (1935)]. It was designed for use with an extension course but also should be useful in the classroom, particularly as a guide for the ambitious student.

Physics Problems and Questions. Franklin T. Jones, 98 p. *University Supply and Book Co.* (Cleveland), 50 cts. Classified lists of elementary problems and questions, compiled from college and examining-board tests by the editor of the physics-problem department of *School Science and Mathematics*.

The Pronunciation of Chemical Words. Committee of the American Chemical Society. 4 p. *Chemical Abstracts* (Ohio State Univ., Columbus), 5 cts. Reprint of the committee report, containing rules for pronunciation and a list of about 360 chemical terms.

Static Electricity in Nature and Industry. Paul G. Guest. 98 p., 11 fig. U. S. Bur. Mines Bull. 368. *Superintendent of Documents* (Washington), 10 cts. A general discussion of static electricity and of industrial hazards and safeguards, with a bibliography.

Trade Booklets and Pamphlets

Carbon Monoxide the Killer. 11 p. *Mine Safety Appliance Co.* (Pittsburgh), gratis. Dangers, sources, and methods of combating carbon monoxide, which ranks fourth as a cause of deaths and occupational diseases and accidents.

Eastman Publications. *Eastman Kodak Co., Medical Division* (Rochester). Available publications include: *Color Films, Plates and Filters for Commercial Photography*, gratis; *Elementary Photographic Chemistry*, $1; *Fundamentals of Photography*, $1; *How to Make Good Pictures*, 50 cts.; *Photography of Colored Objects*, 50 cts.; *Photomicrography*, 50 cts.; *Wratten Light Filters*, 50 cts.; *X-Ray Laboratory Manual*, radiographic principles, apparatus and technique, gratis; *X-Rays and Health*, gratis; *X-Rays in Dentistry*, gratis.

Electronics. *General Electric Co., Educational Sales* (Schenectady), gratis to teachers, 50 cts. per set for class use. Three manuals for instructional purposes: GET-568, *Electronics and Electron Tubes*, fundamental principles; GET-566, *Laboratory Experiments on Electron-Tube Theory;* GET-620, *Laboratory Experiments on Electron-Tube Applications.*

When the Wheels Revolve. 21 p., 49 fig. *General Motors Co., Research Div., Technical Data Sec.* (Detroit), gratis. Very elementary explanations of the simpler mechanisms of an automobile. Good diagrams.

Trade Periodicals

Cenco News Chats. *Central Scientific Co.* (Chicago), gratis. Laboratory and demonstration apparatus, supplies, and methods.

Library Service, College Edition. 9 issues per year. *General Electric Co., Educational Sales* (Schenectady), gratis. Lists of selected physics and engineering articles in current periodicals; announcements of new G-E publications, films, etc.

Radiography and Clinical Photography. *Eastman Kodak Co., Medical Div.* (Rochester), gratis. A magazine with illustrated articles and trade information.

The Educational Focus. *Bausch and Lomb* (Rochester), gratis. Use of optical instruments in science education, especially biology.

The Laboratory. Fisher Scientific Co. (Pittsburgh), gratis. Chemical apparatus and supplies; notes.

Recent Publications

A Manual of Drawing for Science Students. Justus F. Mueller, Assistant Professor of Zoology, New York State College of Forestry. 122 p., 90 fig., 14×21 cm. *Farrar & Rinehart*, $1.75. A clear and interesting presentation of the principles and methods of procedure in simple *freehand* drawing, prepared with the conviction that a reasonable skill in this "simplest and most direct way of communicating what one sees" can be acquired by any college student who is willing to practice the use of a few simple rules.

Seeing and Human Welfare. Matthew Luckiesh, Director, Lighting Research Laboratory, General Electric Company. 193 p., 8 pl., 15×21 cm. *Williams & Wilkins*, $2.50. A nontechnical account of vision, and of the importance of correct illumination and other factors in avoiding eye strain.

DIGEST OF PERIODICAL LITERATURE

Laboratory and Demonstration Apparatus

Inexpensive micro-burner. V. T. Jackson; *J. Chem. Ed.* 12, 216, May, 1935. A piece of Pyrex tubing which is big enough to slip over the barrel and air holes of a bunsen burner is constricted to an internal diameter of 0.5 mm or less and is then cut at the middle of the constriction. The finished tube, which should be about 5 cm longer than the barrel of the burner, is slipped over the barrel and air holes and a gas-tight seal is made at the lower end with gummed paper or sealing wax. This burner gives a hot nonluminous flame which can be varied in height from a few millimeters to 3 cm by regulating the gas supply.

Negative expansion of rubber as a problem for special students. A. Longacre and A. S. Graham; *Sch. Sci. Rev.* 18, 127, Oct., 1935. At Phillips Exeter Academy it has been found desirable to provide special laboratory problems for advanced students. These may take the form of precise measurements with a demonstration apparatus. An example is the demonstration of the negative expansion of rubber under tension, which appears to be mentioned in only one textbook [Edser, *Heat for Advanced Students* (1920), p. 42]. The apparatus, which is simple, includes a connection to the top of the rubber tube from a steam boiler so that the tube can be heated with live steam. The rubber tube used was $\frac{3}{16}$-in. bore, $\frac{3}{64}$-in. walls, and 40 cm long. With a weight of 1000 g hanging from the lower end, the tube stretched 25 cm—well within the elastic limit. Upon passing steam through the tube, it showed a contraction of 5 cm; hence there was no need for magnification by the straw to which Edser refers, even when the apparatus was used to demonstrate to a large class. This demonstration is effective for emphasizing the normal behavior of other materials and for clarifying the anomalous behavior of water by showing a definite case of negative expansion.

For quantitive measurements the rubber tube was suspended inside of a 1.5-cm glass tube which could also be filled with steam. The apparatus was further altered to include a second connection at the top of the rubber tube which went to an aspirator; thus air could be drawn through the tube to hasten its return to room temperature. The procedure consisted in changing the temperature from 20°C to 100°C and back again several times with a given load. Then the load was changed and the procedure repeated. Heating above room temperature was found necessary to produce complete plastic flow when the load was changed. For example, upon changing from working with a load of 100 g to a load of 500 g, a week was allowed to elapse before heating the rubber tube. The length had decreased from 65 cm with the first load to 52 cm with the second. However, upon heating the tube, the first contraction was within 25 percent of that typical for the 1000-g load and about 3.5 times that already known to be typical for the 500-g load. Upon cooling, the tube expanded only to 49 cm, and subsequent heating and cooling checked with the previous data for the 500-g load. All data used were therefore taken after such a preliminary heat treatment.

For loads F greater than 250 g, the coefficient of expansion α decreased proportionally as F increased; thus for the tube investigated, $\alpha=0.00036(1-8.8\times10^{-7}F)$. Hooke's law was obeyed over the range of loads 250 to 1000 g and Young's modulus was computed to be 7.8 megadynes/cm^2 at 20°C.

Edser ends his discussion with the remark: "The legitimate conclusion to be drawn from this experiment is that though india rubber expands when heated, a given stretching force will produce a smaller extension when the temperature is high than when it is low." Thus Young's modulus should have a positive thermal coefficient in the expression, $Y_1=Y_0\,(1-bt)$. From the experimental data it was possible to evaluate the expression directly to read, $Y_1=8.1\times10^6\,(1-2.2\times10^{-3}t)$. Naturally the second differential of the fractional extension is independent of the order of differentiation:

$$\frac{\partial}{\partial F}\left(\frac{\partial l/l}{\partial t}\right)_F=\frac{\partial}{\partial F}\alpha=3\times10^{-10};$$
$$\frac{\partial}{\partial t}\left(\frac{\partial l/l}{\partial F}\right)_t=\frac{\partial}{\partial T}\left(\frac{1}{Y}\right)=3\times10^{-10}.$$

Thus the justification for Edser's conclusion must lie in the fact that tension distortions are more unusual in solids than temperature distortions. In gases, where the distortions are of the same magnitude, however, the two possible points of view are merged into the one gas equation.

Finally the tube was stretched to see if the rubber had deteriorated appreciably during the experiments, and a portion of the tube extended to five times its own length without breaking.

A new use for burnt-out electric lamp bulbs. G. T. P. Tarrant; *J. Sci. Inst.* 12, 92–3, Mar., 1935. Old 100-watt light bulbs provide strong, heat-resisting flasks that are useful especially in experiments in which a glass flask must be destroyed. The bulbs may be opened as follows. Make a wire ring about 2 in. in diameter from No. 18 copper or soft iron wire and attach symmetrically to it three pieces of the same wire. Place the bulb in this ring and twist the three wires together along the axis of the lamp on the side removed from the metal cap. Twist an extra wire firmly round the metal cap and bend its end into the prolongation of the axis. By means of these wires the bulb can be held and rotated in a blowpipe flame without burning the hands.

Rotate the bulb, apply a bushy flame for a few seconds to the glass near the metal, and then narrow the flame down onto the glass-metal junction. As soon as the sodium color appears, stop the rotation and concentrate the flame at one point until a hole is blown in the bulb. Separate the metal cap by rotating the bulb in a medium flame on the glass near the cap, removing from the flame and pulling rapidly. Break off rough corners by tapping with a file. Soften the glass edge by rotation in the flame and shape it with a metal tool.

A simple balance for measuring electromagnetic attractions and repulsions. R. M. Archer; *J. Sci. Inst.* **12**, 105–8, Apr., 1935. The pull of a solenoid is found sometimes by hanging the core from a spring balance and taking readings in various positions, a method which is unsatisfactory in several respects. In the apparatus devised by the author, the pull of the solenoid is measured by a simple lever balance in combination with a spring balance, hysteresis errors being reduced by suppressing lateral movement of the core and keeping the axial movement small. A number of student-experiments can be made with this apparatus.

General Physics and Related Fields

Radium poisoning, a review of present knowledge. R. D. Evans; *Am. J. Public Health* **23**, 1017–23, Oct., 1933. When a few micrograms of radium or other α-particle emitting solid radioactive substance is taken into the mouth or by injection, a fraction of it remains permanently and produces the effect known as radium poisoning. Because of its long half-period of 1600 yrs., radium once fixed in the bones of the victim, produces a nearly constant α-particle bombardment which destroys the blood-producing centers and weakens the bones. Workers who handle radioactive solutions or are exposed to radioactive dust have been victims of fatal anemia; several deaths have resulted from drinking the radium water nostrum "Radithor"; radium solutions used by some physicians to treat such ailments as gout, arthritis, cancer and leukemia may have fatal effects. In general, radioactivity has never been found to be a specific therapeutic agent in internal medicine.

Among the most common symptoms of radium poisoning are necrosis of the jaw, osteogenic sarcoma and regenerative anemia. Regardless of the existence of such symptoms, however, the physician need never remain in doubt as to the presence of radium poisoning, for the physicist offers a number of unambiguous tests such as: ionization chamber-electrometer test of expired air for presence of radon or thoron; γ-ray ionization chamber-electrometer test for radiation from the patient's body; Geiger point-counter and Geiger-Müller tube, placed near the patient's body; tests of a solution of fecal ash or of urine ash with the emanation electroscope; etc. As for treatment, the mobilization of radium through calcium therapy seems at present to afford the only means of removing radium from a victim's body.

"Activated" water is to be distinguished from radium water. The latter contains actual radium salts, and hence is permanently radioactive and dangerous. "Activated" drinking waters from emanators and other devices, and also radium spring waters, contain merely the short-lived gas radon. No deaths have been traced to their use but neither is there any clinical evidence that they are beneficial. Those activators in which the water comes into contact with the radioactive source are dangerous when the material is dissolved appreciably, for then the product is radium water.

It must be emphasized that the modern use of radium in the treatment of cancer cannot result in true radium poisoning; only the penetrating γ-radiation is utilized, and then only for definite, limited times of exposure, and hence no radium enters the patient's system. Overdoses of γ-rays will produce pernicious anemia and myeloid leukemia as late as 4 years after a massive exposure, but these effects are to be regarded as radiation burns rather than poisoning.

Continuity of the solid and the liquid states. J. Frenkel; *Nature* **136**, 167–8, Aug. 3, 1935. It was believed until recently that liquids were in all respects—save their density—more similar to gases than to solids, and this view was strengthened by the van der Waals theory of the continuity of the liquid and gaseous states. But new facts have corroborated the view that liquids—at least near the melting point—are much more like solids than gases, with respect not only to density but to the character of their *heat motion* and *structure*. Ten years ago Frenkel pointed out, among other things, that the heat motion in simple liquids consists of vibrations about an equilibrium position which, after an average time depending in part on the temperature, is shifted through a distance comparable with the interatomic distances. Recently Pauling and others have pointed out that the molecules in a crystalline solid can rotate more or less freely—just as has been assumed for liquids and gases; and Debye has shown that both in liquids and solids there is actually no *free* rotation, but a sequence of rotational oscillations about an equilibrium orientation which is changed abruptly from time to time. Finally, Stewart and others have found that the x-ray diagrams of liquids, especially near the melting point, are very similar to those of a microcrystalline solid. The process of melting, therefore, is not a sharp transition from the crystalline to the amorphous state: near the melting point, the solid is no longer exactly crystalline but contains a number of "dissociated atoms" or ions which are irregularly distributed in the "interstices" of the crystal lattice and form the beginning of the amorphous phase within the crystal; and the liquid after melting is to a great extent crystalline but becomes gradually more amorphous as the temperature is raised.

The fact of the existence of a sharp melting point thus does not contradict the continuity of the solid and liquid states, but simply indicates, just as the boiling point does in the case of a gas, that a continuous transition from solid to liquid must go through a sequence of unstable states, characterized by the same hook-like shape of the P-V curve as occurs in the van der Waals isotherms below the critical temperature. Above the critical temperature T_1, the hook corresponding to the boiling point disappears, whereas the

one for the melting point remains, since, as has been shown by Bridgman, and especially by Simon, it is possible to obtain under sufficiently high pressure a substance in the solid state above its critical temperature. A critical temperature $T_2 > T_1$ for which the hook corresponding to the melting point disappears does not exist, but it is very probable that there is a critical temperature $T_0 \gtrless T_1$, connected with a strongly negative value of the pressure, at and below which it should disappear, and where there is a fusion of the solid and liquid into a single "condensed" state. Some qualitative details of Frenkel's theory of fusion are given in this paper but the mathematical details are yet to be published.

MISCELLANEOUS

The unemployment situation for Ph.D.'s in mathematics. E. J. MOULTON; *Am. Math. Mo.* **42**, 143–4, Mar., 1935. A survey of 50 American universities made by a Commission of the Mathematical Association of America shows that early in 1934 there were about 120 persons holding the doctorate in mathematics who were seeking positions and 60 others who were about to receive the degree who also would want employment; many of these held positions of some kind, in most cases temporary ones. In October, 1934 at least 14 of the 180 were still unemployed and 25–35 held low-salary assistantships or positions in no way related to their special training. In many cases persons recently granted the doctorate have been retained on appointments that normally would have been awarded to graduate students thus partially passing on the burden of unemployment to the latter.

As many doctorates in mathematics have been conferred since 1925 as were altogether prior to that time. A fairly recent survey of 1098 institutions in the United States and Canada, including junior colleges and degree-granting normal schools, showed that they employed 3488 mathematics teachers, of whom 937 held the doctorate. Normally one would expect about 100 replacements annually in these institutions due to retirement, resignations and deaths. Even when account is taken of the fact that some of these institutions may regard other qualifications and preparation more important than the training afforded by the doctorate, it appears that the demand for Ph.D.'s in mathematics in the near future probably will exceed the present rate of supply. This seems more certain because many of those now working for the degree are already employed, so that new positions will not be needed for them.

Because of salary conditions in the colleges, many Ph.D.'s may find positions in secondary schools attractive and the Commission points out that it would be wise for a candidate for the doctorate to note particularly the requirements for teachers in the secondary field.

Appointment Service: Positions Wanted by A. A. P. T. Members

The physicists whose announcements appear here are not at present employed in professional capacities. Representatives of departments having vacancies are urged to write to the Editor for additional information concerning those whose announcements interest them. *The existence of a vacancy will not be divulged to anyone without the express permission of the department concerned.*

1. Ph.D. Cornell, S.B. Denison. Married. 20 yr. teaching experience, including 5 yr. assoc. prof. state college and 5 yr. head of dept., southeastern univ. Special interest in undergraduate teaching and in building and adapting laboratory apparatus to suit the needs of the student.

2. Ph.D. Indiana, M.S. Kansas State, A.B. Friends Univ. Age 31, married. 2 yr. asst. instr. state univ.; 1 summer, instr. Kansas college. Special fields: conduction of heat and electricity in metals; electrical communication; physical chemistry. Desires position in undergraduate teaching or industrial research.

3. Ph.D. Univ. of Washington, B.S., M.A. Northwestern. Age 45, married, no children. 11 yr. civil engineering work; 15 yr. teaching physics, including 8 yr. college in Orient and 4 yr. head dept. western coed. college. Special fields: magnetism, engineering physics, history of physics. Experienced administrator and executive.

4. Ph.D. Cornell. Age 38, married. 11 yr. teaching in both men's and women's colleges in East and South. Research in electron physics. Special interest in development of demonstration lectures, laboratory experiments and equipment. Glass blowing.

5. Man, 30, married, Ph.D. Yale. 6 yr. teaching experience in eastern universities in most branches of undergraduate physics for both men and women; 3 yr. research associate in radiology in prominent medical school. Supervision of master's theses; research in nuclear physics and thermionics. Broad interests.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge. Departments of physics having vacancies of any kind and industrial concerns needing the services of a physicist are invited to make known their wants through the columns of this journal; there will be no charge for the service. For additional information, address the Editor.

AUTHOR INDEX TO VOLUME 3

In this index are listed the names of the authors and the titles of their articles. Articles that are abstracted in the "Digest of Periodical Literature" section of the journal are not listed; they will be found indexed in the *Analytic subject index*.

ANALYTIC SUBJECT INDEX TO VOLUME 3

In this subject-index the titles of articles are disregarded, the entries being based on analyses of the contents of the original articles. Entries marked (D) refer to digests which appear under "Digest of Periodical Literature" in the journal; entries marked (R) refer to reviews which appear under "Brief Notices of Recent Publications" and "Teaching Aids."

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CONTENTS

AM. PHYS. TEACHER 3 (1935) DECEMBER

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